metal treatment and Drop Forging

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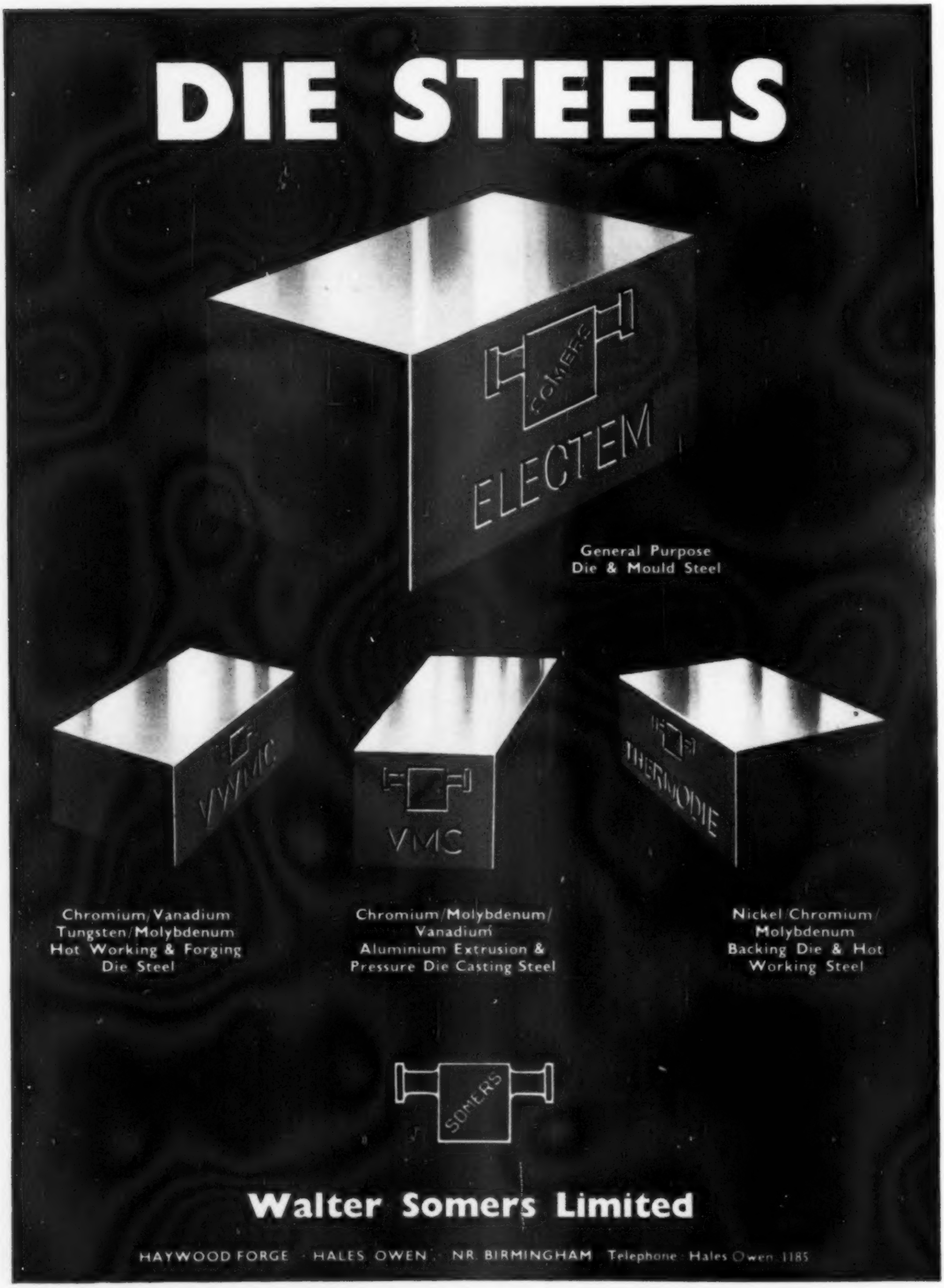
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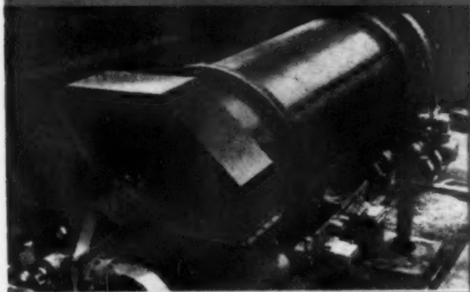

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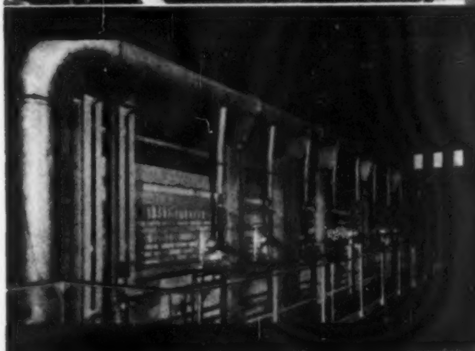

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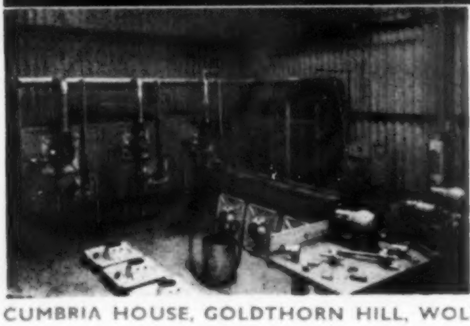

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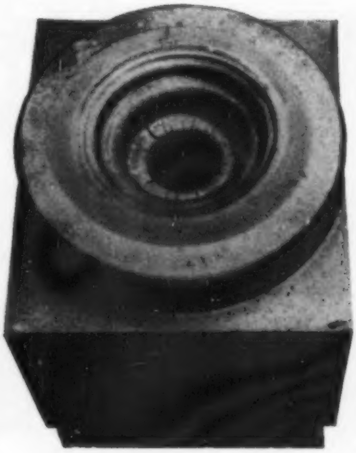

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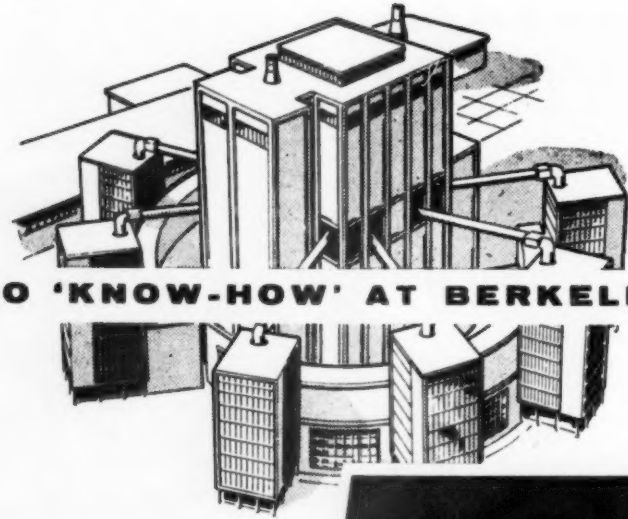

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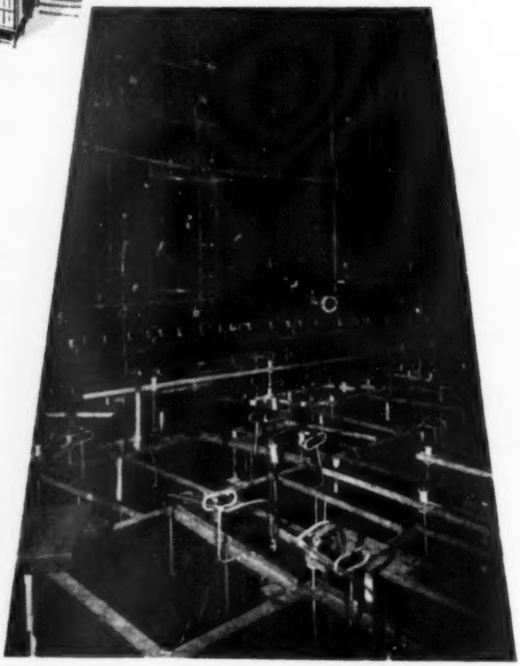

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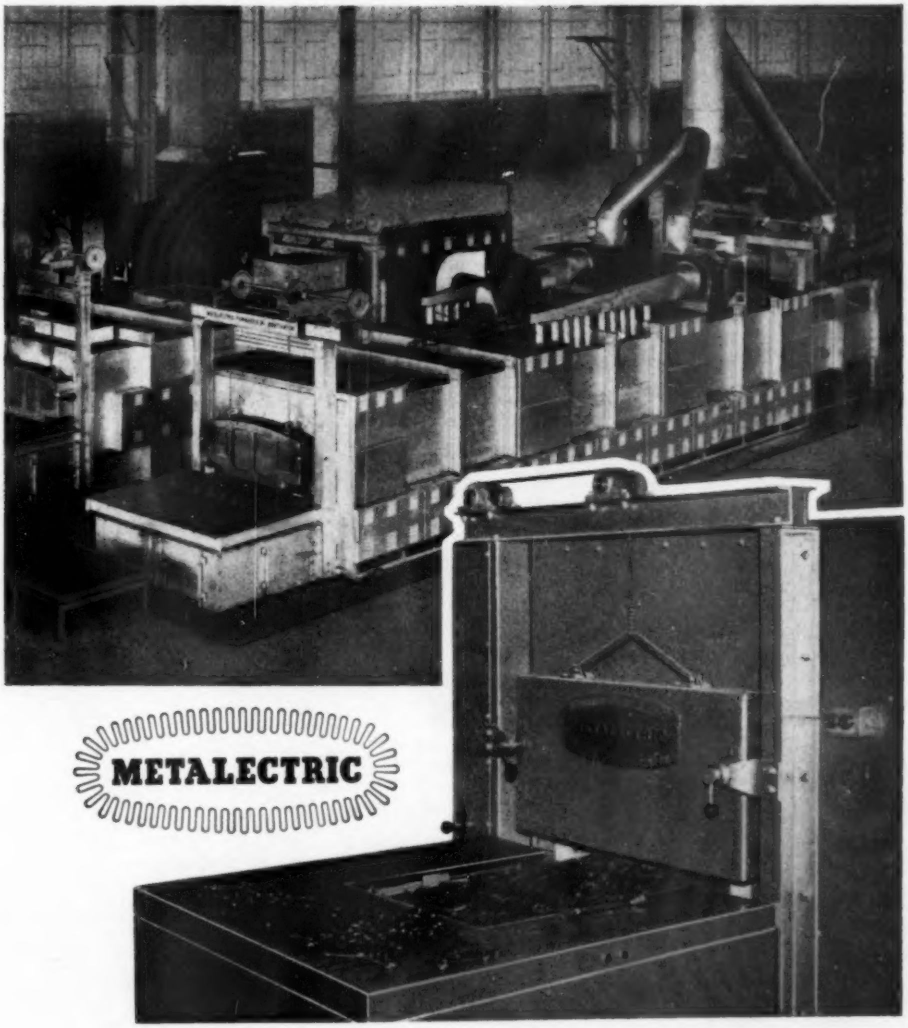
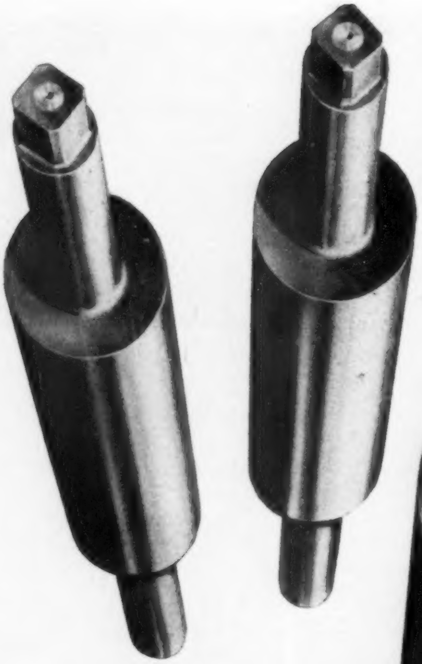




Britain's new steelmaking processes set challenge to steelmen

The next ten years will be decisive for the future of Britain's steel industry. New methods are being developed which will change the established pattern of steelmaking. It is an exciting–and challenging–time.

The big new factor is oxygen. Ordinary oxygen from the air we breathe, but used as a pure gas, *by the ton*. In making steel it removes impurities more quickly and more cheaply than has ever been possible before.

New oxygen-making plant is being set up alongside the major steel works to deliver the gas along pipelines. About 3,000 tons of oxygen a day will soon be available.

Output: a 100% boost

Dr. Colclough, technical adviser to the British Iron and Steel Federation, has been a crusader for oxygen for 20 years. The great change that is making his vision practicable is that oxygen by the ton ("tonnage oxygen") is now available at a reasonable price.

FEDERATION'S COLCLOUGH
Crusader for oxygen

Dr. Colclough believes that, in Britain, oxygen can be used with greatest effect in the open hearth process, by which 85% of our steel is made. He says, "There is no question but that in the next ten years we shall see a revolution in open hearth steelmaking." Already, at the Appleby-Frodingham works in Lincolnshire, the open hearth furnaces converted to the Ajax process, using oxygen, have achieved outputs of up to 100% above those of conventional furnaces.

"The industry has gone a long way to solving the problems of using tonnage oxygen," says Dr. Colclough, "and many major steel developments of the future will be based on this principle. And by equipping the new oxygen-using plants with dust and smoke eliminators we are reducing the amount of air pollution caused by steelmaking."

New furnace, new methods

Another enthusiast for oxygen – though using it in quite a different way – is Mr. Emrys Davies, Works Director of Brymbo Steelworks in North Wales, which pioneered the large-scale use of oxygen.

At Brymbo, after the war, they had a blast-furnace (for making iron) and some old open-hearth furnaces (for turning the iron into steel). They were also making high-quality steels in electric arc-furnaces, mainly from scrap – because iron from a blast-furnace is much too impure to put into an arc-furnace.

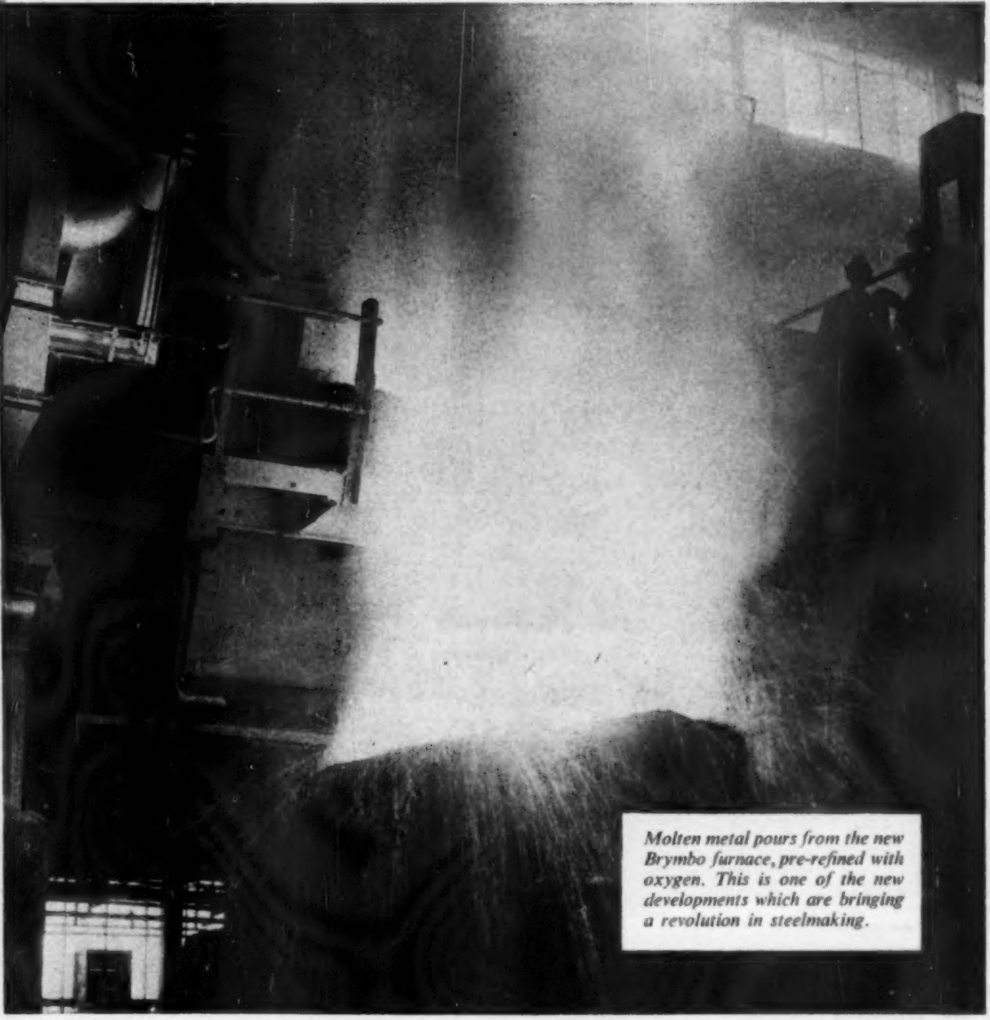
BRYMBO'S DAVIES
Steel at the cross-roads

They wanted to go over entirely to electric steelmaking. But it looked as though this would mean that they couldn't use the iron from their blast-furnace at all. Mr. Davies and his team developed an oxygen-blown furnace of wholly new design, to pre-refine blast-furnace iron before it went to the electric arc-furnaces.

Here are the makings of another revolution – because electric steelmakers have been chiefly dependent on supplies of scrap. Reducing this dependence could be very important – so much so that steelmakers as far afield as Japan are extremely interested in what is going on at Brymbo.

Less power, more steel

This completely new process has been embodied, daringly, in a £2 million development scheme, now proving its worth in full production. It has cut the time taken for the arc-furnaces to refine a charge of metal. It has reduced the electric power needed to refine a ton of steel from 650 units to 400 (quite important, when you consider that the Brymbo melting shop uses 10 times as much power as the whole of the nearby town of Wrexham). Outputs are up



Molten metal pours from the new Brymbo furnace, pre-refined with oxygen. This is one of the new developments which are bringing a revolution in steelmaking.

at least 25% – "a very conservative figure," according to Mr. Davies.

And whereas a Bessemer converter needs re-lining with special bricks after being used 80 to 100 times, the Brymbo pre-refining furnace has already been used 1,000 times. It has produced 25,000 tons of steel and will probably produce 10,000 more before re-lining is needed.

Most important of all, perhaps, the Brymbo process has signposted one possible way ahead for the whole industry: pre-refining can be applied just as successfully to open-hearth working. "Steel is at a cross-roads," says Mr. Davies. "The next decade of steelmaking will probably be the most interesting for 100 years. Great developments are taking place."

Oxygen is coming into its own, taking its place alongside iron ore, coke, and lime-stone, as a basic raw material in steelmaking. Already Britain's steel men can see that it brings higher output and lower costs. It will mean an all-round improvement of efficiency in Britain's already highly efficient steel industry.

This report on progress in oxygen steel-making forms part of the "Autumn report to the Nation" published in the press by the British Iron and Steel Federation.

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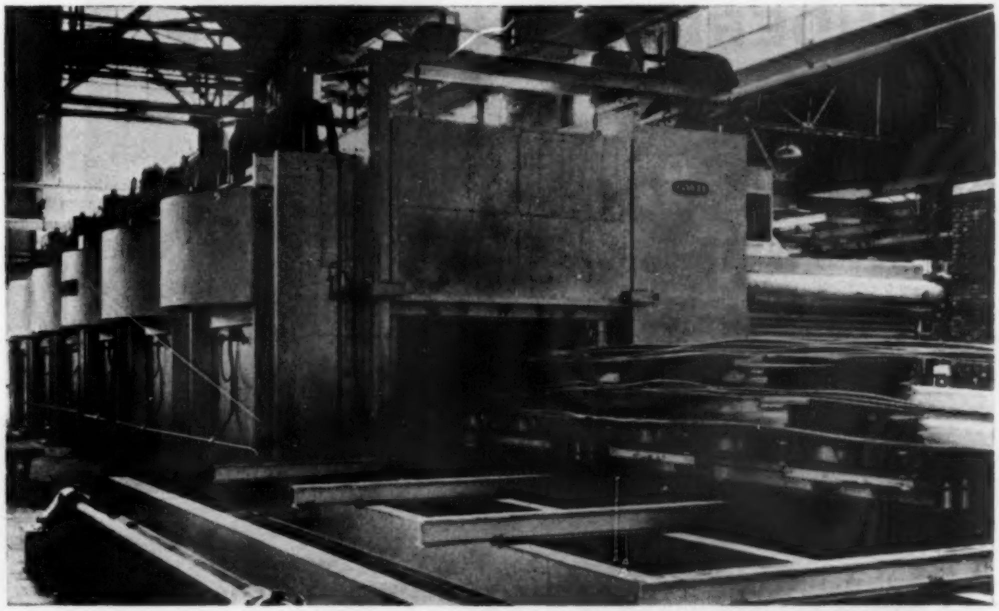

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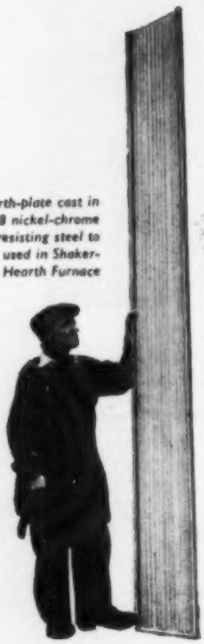

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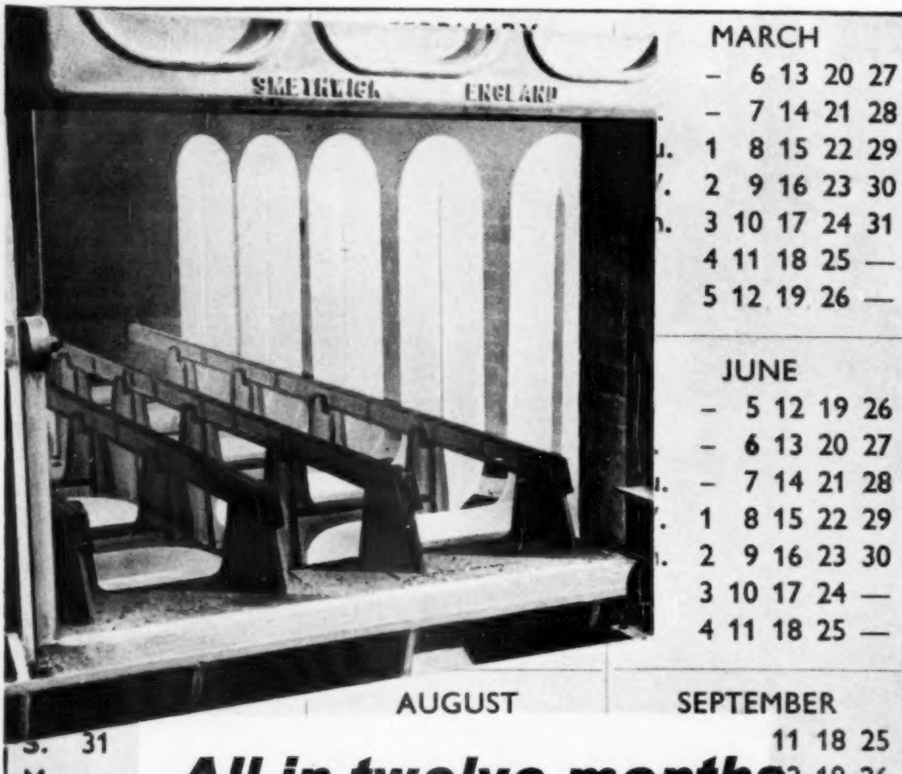
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CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

Silver Jubilee

ONE of the hallmarks of an advanced civilization is the ability to record historical events. This ability depends not only on the possession of a system of writing but also on the knowledge required to measure the passing of time in an objective and predictable manner. The calendar, in earlier times, was looked upon as supremely important, especially as its use was required to observe the great festivals and feasts. Nowadays, when our public holidays are only a shadow of what they were in more closely integrated communities, we still make good use of our calendars to keep track of our own private anniversaries. It is often said that anniversaries provide us with excellent reminders to stop a moment and take stock, and we welcome the opportunity in this issue to take a look at the scene twenty-five years ago when METAL TREATMENT first appeared as a quarterly journal. It may be of interest to quote from a leading article on the subject of policy, which appeared in the autumn 1935 issue.

' In so far as the articles are concerned, the policy of METAL TREATMENT is to provide a medium for descriptions of plant and operations, expressions of views and opinions, narrations of experiences in the use and treatment of metals, reviews of developments in knowledge and practice and for announcements of new discoveries and innovations. Articles of all these types contribute to progress and are of interest to all concerned with metals in whatever capacity. There is, however, another aspect. So far, we have been talking about this country, but a vast amount of important information is being acquired and circulated abroad. This is not so readily available to British readers as are the proceedings of our own Institutes. There is the difficulty of getting access to all the journals, transactions, and proceedings, the difficulty of finding time to read them, and sometimes the language difficulty. In order to assist in the dissemination of important information from abroad, we are making a feature of abridged versions of American papers, and translations from German and French.

'Abstracting is an extensive activity today, and in view of the purpose that abstracts serve, completeness is the essence of the matter. This makes them reliable sources of reference when something definite is sought, but difficult to read for general information. In our review, we aim at something between abstracts and abridged articles. In the first place, it is selective, and confined to papers and articles that are definite contributions to knowledge, interesting descriptions or reliable reviews. Furthermore, it is confined to publications that can be so dealt with as to indicate their substance in comparatively few words; and finally, on account of the ready availability of British journals, it deals mainly with material published in other countries.'

It seems to us that the points made in this Editorial twenty-five years ago are as valid today as when they were written. In fact, the case could be put even more strongly now in view of the increased number of specialized techniques, the vast amount of literature produced, and the multiplicity of languages in which important work is reported—certainly we can no longer restrict ourselves to only German and French. In the same way as the industrial world has widened to include countries hitherto ignored, so has the field of treating metals stretched its boundaries to include techniques and materials which were not even thought of when this journal first appeared. To give but one example from the present issue, the article by Dr. Wright on ' Metallurgy in nuclear power technology ' shows the increasingly wide front with which the metallurgist has now to contend. Since autumn 1948, we have also been the official organ of the National Association of Drop Forgers and Stampers, and the important field of chipless shaping of metals has received due recognition in these pages. We believe that the policy laid down in 1935 has been the firm foundation on which this journal has been built, but it is a foundation which permits of a flexible superstructure which should well be able to accommodate itself to whatever changes the next twenty-five years may bring.

Stainless steel in architecture

One of the most marked changes in our cities during the last quarter of a century has been the introduction of metal curtain walled buildings. Although the idea of the curtain wall had been known since 1883, it required some 50 years for its recognition as a means to a new architectural form. The rapidly increasing use of metal in this field has brought its metallurgical problems, but it has also proved a challenge to architects and it is instructive to see the other side of the picture.

A lecture on 'Recent developments in the architectural uses of stainless steel in the U.S.A.' was given by Prof. G. E. Danforth, A.I.A., last month at 66 Portland Place, W.1. The lecture was presented by the Stainless Steel Manufacturers' Association, by courtesy of the Royal Institute of British Architects. Illustrated by two sound/colour films and approximately 90 slides, the lecture dealt with the case histories of five important buildings in the U.S.A. and one in Canada.

To support the lectures an exhibition of the uses of stainless steel in architecture was brought from the U.S.A. Exhibits included scale models of buildings, actual examples of curtain wall panels, window frames and other applications in stainless steel and a range of available forms, giving some indication of the workability of the metal.

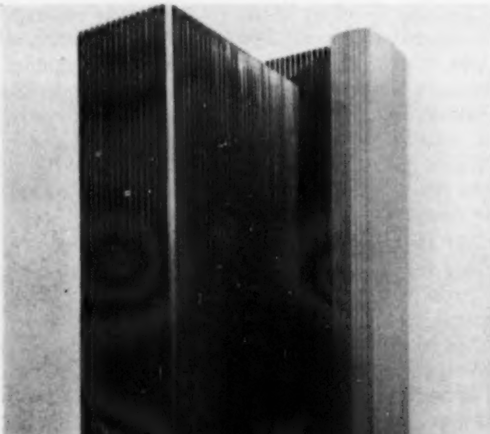
In his introductory talk, Prof. Danforth, director of the Department of Architecture at the Illinois Institute of Technology, Chicago, U.S.A., and one of America's leading authorities on the uses of stainless steel in architecture, made the following points in a very clear summary of the historical background.

BEFORE THE BIRTH of the steel frame in 1883 the methods of architectural construction had gone unchanged for tens of centuries. The post and lintel characterized the temples of early Egypt and later the Renaissance. The arch was the structural system of the Romans. The 12th-century Gothic builders, not possessing large building stones, developed the dynamic skeleton of pier and vault, a product of the earth rising upward as a tree into a structure imbued with a kind of magic.

The industrial revolution of the 19th century more than anything in the history of man affected the fundamental character of architecture, not to speak of the whole fabric of the civilized world. We have but to compare the Pantheon to the Crystal Palace, built in 1851 in London to house the Great Exhibition, to show what portended a new architecture which is as founded in logic and

continued on page 41

Gateway Center No. 4, Pittsburgh, Penn.



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Effect of carbide stringers on the distortion of die steels during heat treatment

K. SACHS, PH.D., M.SC., A.I.M.

The causes and mechanism of distortion of die steels during heat treatment, the influence of the structure of the steel and in particular the part played by carbide stringers, are studied. The author is Head of Research, Metallurgy Section, G.K.N. Group Research Laboratory, Wolverhampton, and his article will be continued in future issues

MAN DIFFERS from animals in using tools. Civilized man differs from primitive man in making his own tools. Civilization and technical progress are based on man's reluctance to do unnecessary work—or to pay others to perform unnecessary work. Having made a tool, civilized man likes to use it for as long as possible and to produce as many components as possible with it. Over the years, experience has taught us what properties steel must possess if it is to have a long, useful life and how to make the best use of these properties.

A tool for forming or cutting metal will suffer wear in repeated use and become blunt or lose shape. Experience shows that wear resistance increases with hardness, and engineers have become better at coping with brittleness, the principal concomitant disadvantage of increasing hardness. Of course, the harder a tool, the more difficult it is to make in the first place. The ability to shape steel into a tool while soft and to harden it effectively afterwards was one of the more important stimuli in the period of rapid acceleration of technical progress which historians dramatize by the label 'industrial revolution'—it will be recalled that the early development of the steam engine depended on the ability to bore a cylinder with some semblance of accuracy.

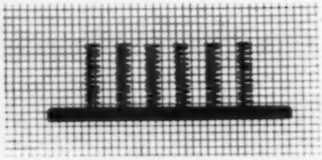
Mass production and the use of interchangeable components accelerated the demand for closer accuracy of work and this was reflected in a need for greater precision in tooling. When tools are machined to high accuracy, slight distortion in hardening may render them useless. Some errors can be corrected by grinding, but this is an expensive operation.

Some slight distortion during heat treatment has to be accepted as unavoidable in this imperfect world. The extent of distortion in a particular application will be reproducible within certain limits, but some scatter is again quite unavoidable. If the tools are machined with a grinding allowance which makes it possible to correct the worst distortion likely to occur, a considerable amount of grinding has to be done on all tools, even those showing very little distortion. If, on the other hand, the grinding allowance is reduced to cut overall grinding costs, the risk of having to scrap an occasional tool is increased. The precise economic balance is doubtless a matter for detailed statistical investigation, but tool-room engineers probably achieve the correct balance by experience based on years of trial and error. Meanwhile, they would undoubtedly welcome anything that could be done to reduce, not only distortion, but also variability of distortion in heat treatment. It is with this general object in mind that I propose, in this article, to review the causes and mechanism of distortion, and the influence of the structure of the steel, paying particular attention to the part played by carbide stringers.

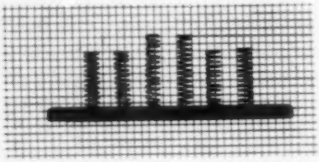
Causes of distortion

Distortion, a change in shape or dimensions, occurs as a consequence of a modification in the distribution of internal stresses. All changes in shape or dimensions are changes in the relative position of atoms and are a direct reflection of the exertion of force, the imposition of a stress; an external force deforms metals, an internal stress distorts them. Internal stresses are set up when changes of dimensions due to external forces are not distributed uniformly in the component. Changes in dimension can be caused by three factors: (*a*) plastic deformation, (*b*) removal or addition of metal, and (*c*) dilatations due to changes of temperature or structural transformation.

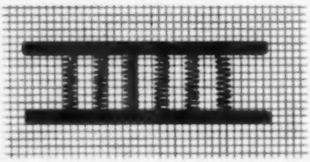
It has been found convenient to illustrate the operation of internal stresses by models in which the



1 *Model of undistorted unstressed metal*



2a *Model of separate layers*



2b *Layers locked together in block of metal. Stresses are in balance to give equilibrium shape*

a *Original shape*

b *Deformed by application of stress*

c *Stress relaxed—one layer is plastically deformed*

d *Symmetrical model deformed by stress*

e *Stress relaxed*

3a–e *Models showing effect of adjacent layers with different mechanical properties*

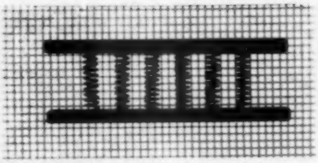
metal is represented by a group of coil springs. In fig. 1 all the springs are of equal length—no dimensional changes have been imposed on the metal; when the top end of the springs is joined by a bar similar to the one at the bottom, there is no change in the system because no stress is imposed on any spring—the internal stress is zero at all points in the metal and therefore the resultant stress is also zero.

Internal stresses are produced when springs of unequal length, like those in fig. 2 (*a*), are locked into a closed system representing a piece of metal, as in fig. 2 (*b*). Now, the outer springs are stretched, the inner ones squeezed together—the outer layers of the metal are in tension, the core is in compression; there are internal stresses at different points of the metal and the system has arranged itself in such a way that these internal stresses are balanced, *i.e.* that the resultant of all the internal stresses is zero.

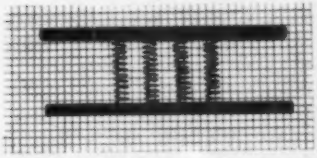
Any change in the balance of internal stresses would lead to a finite value of the resultant stress and the metal would change its shape under the action of this stress until the internal stresses are in equilibrium again. Thus distortion can be defined with reasonable precision as the change in shape or dimensions which reduces the resultant of all the internal stresses to zero. The way in which non-uniform dimensional changes lead to distortion will be illustrated with the aid of simple coil spring models in the following three sections.

Plastic deformation

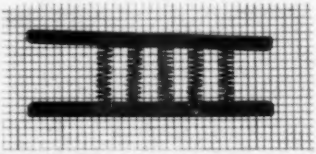
A uniformly applied stress in excess of the elastic limit changes the shape of the metal; when the stress is relaxed the elastic part of the deformation



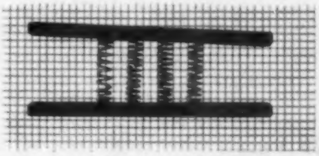
4a *Model of metal with internal stresses*



4b *Outer layer removed uniformly by turning and etching*



4c *Outer layer removed on one side only by milling or shaping*



4d *Outer layer removed first from one side, then the other, with plastic deformation at the intermediate stage*

recovers, but there has been no disturbance of the equilibrium, no distortion. In the shaping of metals the stress is not necessarily applied uniformly; in any case the elastic limit will not always be uniform throughout the metal.

A piece of metal with adjacent portions differing in elastic limits can be represented crudely by two similar coil springs, one of which has been annealed. Before the application of stress the shape is perfectly symmetrical (fig. 3 (*a*)). When this model is loaded in such a way that the stress is intermediate between the elastic limits of the annealed and hard springs, the former suffers plastic extension while the latter is deformed elastically, as shown in fig. 3 (*b*). When the load is removed and the stress relaxed, the annealed spring will be longer than the hard one and the model will show severe warping (fig. 3 (*c*)). If the arrangement of springs is symmetrical (fig. 3 (*d*)), there will be no warping and the shape of the model will remain symmetrical, but the resultant stress will impose a dimensional change intermediate between the length of the annealed and hard springs after relaxation of the external stress (fig. 3 (*e*)).

Thus, non-uniform plastic deformation leads to distortion and asymmetry of the irregularities leads to warping.

Removal or addition of metal

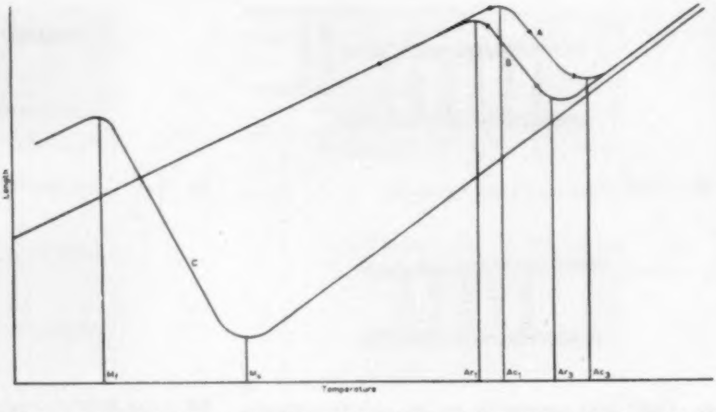
In principle, removal or addition of metal does not cause internal stresses but redistributes them so that the equilibrium is changed, as will be shown in some detail. In practice, however, the methods employed often introduce stress into the surface layers due to plastic deformation (machining), thermal and transformation stresses (weld deposition), or elastic stresses (electro-deposition). Distortion due to redistribution of internal stresses is most conveniently considered in terms of the removal of metal by etching, electro-polishing, or a careful machining operation which does not confuse the issue by introducing plastic deformation.

The original piece is in equilibrium, *i.e.* the resultant internal stress is zero; if this is due to the absence of local internal stresses, the stress-free removal of metal will not disturb the equilibrium, but if it is due to a balance of localized stresses removal of metal will distort the work-piece.

A piece of metal with symmetrical internal stresses can be represented by a model in which springs of unequal length like those in fig. 2 (*a*) are locked together, as in fig. 2 (*b*). This model is reproduced again in fig. 4 (*a*). The removal of metal from both sides simultaneously, as in uniform etching or in turning, is represented by the removal of the two outer springs. These were in tension, so that their elimination relaxes the compression on the two middle springs and increases the tension on the remaining ones; in other words, the elimination of some of the tensile stress produces a resultant compressive stress which expands the model, as shown in fig. 4 (*b*).

If one side is masked during etching, or the work-piece is milled or machined on a shaper, the correct analogy is the removal of a spring from one side only. This again removes some stressed material so that the resultant is no longer zero; all the springs will extend a little and the asymmetry of the tension springs that have been left in the assembly will pull the whole model over. In the bent model in fig. 4 (*c*), representing a warped work-piece, the reduced tension due to removal of a tension spring will be balanced by some relaxation of compression due to an overall extension of all the springs and when the shape is stable the resultant stress is again zero.

It is difficult to predict precisely what happens



5 *Dilation of steel*

when metal is removed first from one side, then from the other. If the outer springs are removed alternately, the model goes through the stage illustrated in fig. 4 (*c*) and should finally reach the condition shown in fig. 4 (*b*). However, there are two factors that may result in the final component being warped: (*a*) the material may undergo plastic deformation at the stage reached in fig. 4 (*c*), *i.e.* one of the springs would receive a permanent set, resulting in the shape shown in fig. 4 (*d*); (*b*) when a bent component as in fig. 4 (*c*) is dealt with, some of the inner layer may be removed, leading to even more complex warping.

Further complications due to asymmetrical internal stresses in the original piece, or due to non-uniform mechanical properties, can be postulated without difficulty. It is less easy to visualize or illustrate their precise consequences.

Thermal and transformation dilatations

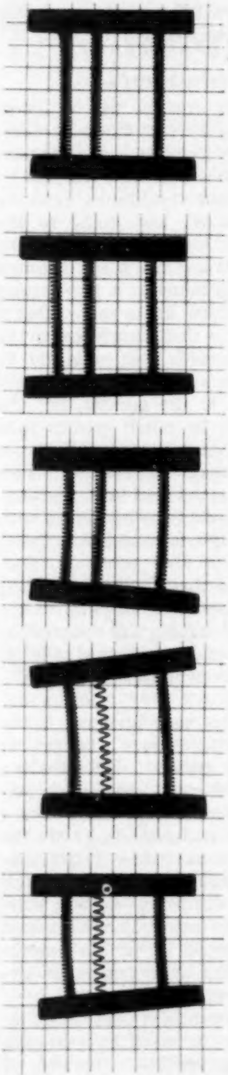
During the heating and cooling cycles involved in the heat treatment of steel, the metal undergoes complex dilatations. In addition to the habitual expansion on heating and contraction on cooling, there are isothermal contractions when austenite is formed and isothermal expansions when austenite breaks down.

Typical dilatation curves are shown in fig. 5. Curve *a* shows what happens during heating: a gradual expansion, a sharp contraction between Ac_1 and Ac_3, followed by further expansion characterized by a slightly steeper slope. Cooling at moderate rates (curve *b*) reverses the procedure and there is an initial contraction extending to temperatures rather lower than Ac_3, owing to slight undercooling of austenite decomposition; expansion is observed at Ar_3, completed at Ar_1, and contraction continues along the ferrite line. Curves *a* and *b* thus demonstrate the hysteresis of the austenite-ferrite transformation. Curve *c* shows the effect of rapid quenching. Austenite is retained down to M_s and contraction of this austenite between Ar_3 and M_s is steeper than the contraction of ferrite over the same temperature range; between M_s and M_f, martensite is formed, accompanied by an appreciable expansion.

When the rate of heating or cooling is low, so that the temperature is virtually uniform throughout the metal, all these dilatations are equally uniform and no internal stress is set up. When heating or cooling is fast there is an appreciable temperature gradient across the section, so that some layers will expand or contract more than others and at different times, and this irregular distribution of dilatations will set up internal stresses. A large piece of metal cooling down at a sufficiently fast rate for the outer layers to contract more than the core can be represented by an assembly of springs of unequal length, as in fig. 2 (*a*). When this assembly is locked by placing the upper bar in position, as in fig. 2 (*b*), the outer layers are in tension and the core is in compression. The same stress system is set up on heating, when the outer layers contract on forming austenite in advance of the core. Thermal expansion on heating, or as a result of austenite transformation, reverses the stress system, so that the core is in tension and the surface in compression.

This reversal of stresses is particularly important in the quenching of engineering steels containing sufficient carbon to have a fairly low martensite transformation temperature, because the contraction of austenite will have proceeded further along the steeper branch of the curve, and because the transformation of austenite to martensite is accompanied by a profound change in mechanical properties.

These effects can be considered most easily with the aid of an example, and it is proposed to do so by following what happens when a large piece of steel is quenched. The surface contracts more quickly than the core and is in tension, while the core is in



a *At furnace temperature*

b *Cooling to M_s*

c *Thin wall below M_s, thick wall above M_s*

d *Thick wall above M_s; austenite deformed plastically in tension*

e *Below M_f*

6a-c *Model of thick-walled tube with eccentric bore*

compression. When the surface reaches the M_s temperature and begins to expand, the stresses are gradually relieved, but, as the piece continues to cool, the surface expands progressively and the thickness of the expanding surface layer grows, while the core continues to contract as it cools down to M_s. As a result, the stress system at a time when the core is above M_s and a substantial surface layer has formed martensite, will consist of tension in the core and compression at the surface. On further cooling, the temperature of the surface layer passes M_f and it starts to contract, while the core begins to form martensite and expands; this reverses the stress system again, and when the whole piece of steel is at room temperature, there should be no internal stress left.

It is possible, however, for the stresses during cooling to exceed the elastic limit. This is particularly likely to happen while the outer layers are transforming and expanding and the core is still contracting because the dimensional changes are particularly sharp and because the core is still austenitic and, therefore, has a much lower elastic limit than the martensitic outer layers. When the core subsequently expands on further cooling, its final extension will be increased by the plastic deformation it has undergone and at room temperature the core will be in compression and the surface in tension. This stress could relax only if the surface layer were to deform plastically while the core expands, to balance the earlier plastic deformation of the core. This is perhaps possible in some steels and would lead to considerable expansion over the original dimensions, but is not likely because the surface layers are already martensitic and a high stress due to expansion of the core is likely to produce quench cracks rather than plastic deformation.

Even more dramatic is the warping that can occur when a non-symmetrical body is quenched. Fig. 6 (*a*) is a simple model consisting of three springs, one being separated from the other two by a gap; it represents the cross-section through a tube with an eccentric bore. At the furnace temperature the model is straight and there is no internal stress. The thin wall cools and contracts more quickly than the thick one, so that when the temperature is just above M_s the thin wall is in tension, the thick wall in compression and the model is bent towards the thin wall (fig. 6 (*b*)). When the temperature of the thin wall passes M_s it begins to expand, while the thick wall continues to contract until its temperature has also fallen to M_s; the thin wall is now in compression, the thick wall in tension, and the model bends the other way (fig. 6 (*c*)). The stress is so severe that some of the austenite suffers plastic deformation; the tension is highest near the bore and this is where plastic extension takes place (fig. 6 (*d*)).

On further cooling the thick wall expands as austenite transforms, while the thin wall contracts on normal cooling. The plastic extension is not recovered and, in fact, enhances the expansion, although this is a second-order effect. The shape of the model at the end of the treatment is determined by the plastic extension of part of the thick wall,

represented by a slightly longer, plastically stretched spring. Since the spring is longer than the others, it is in compression, the other two are in tension, and the model bends towards the thin wall again (fig. 6 (*e*)).

It can be concluded that some dimensional changes are unavoidable in the course of heat treatment. Rapid cooling of substantial sections leads to internal stresses, which will modify these dimensional changes. If the design of the component or the cooling conditions favour asymmetry of the internal stresses, it is not only the dimensions but the shape of the component that is altered—*i.e.* the component is warped. If the internal stresses are severe enough, and particularly if they are assisted by stress-raisers in the form of sharp changes of section, they may lead to localized fracture of the steel, *i.e.* quench cracks.

Distortion during toolmaking

It is evident from this brief review of the causes of distortion, that the many operations involved in making a large die are bound to create opportunities for each of the causes to operate. Dies are machined from blocks of steel, cut in the first instance from forged bars of appropriate section. These ought to be free of internal stresses, but, if forging has continued to fairly low temperature, recrystallization and recovery may not be complete. There have been suggestions lately that some plastic deformation effects, perhaps in the form of exceptionally stable dislocation networks, can survive in nominally recovered and even recrystallized material. Moreover, large sections—it is always risky to mention figures, but sections larger than 2½–3-in. square—may develop cooling stresses even on air cooling.

Since toolmaking is a very expensive process, the additional expense of heat treating the block before machining is only a small fraction of the total and is justified by the relief of internal stresses, which reduces the risk of distortion during machining, and by the attainment of a more uniform structure. It is good practice to give the block a full anneal before machining is started, but in some cases normalizing, or a sub-critical stress-relieving treatment, is found more convenient.

The machining operation inevitably cold works the surface and this may cause slight distortion in subsequent machining. With complex die shapes a lot of material may have to be removed from some areas and the heavy cuts necessarily employed if this is to be accomplished in reasonable time may deform quite a thick layer at the surface. This may not be removed entirely in subsequent fine machining operations. Sub-critical anneals are often interspersed in the machining sequence, most frequently between the roughing and finishing stage, and sometimes when the block has to be turned over. A final stress relieving or even full anneal is generally recommended before heat treatment.

Distortion during heat treatment

The operation where the greatest risk of distortion occurs is undoubtedly heat treatment. Some troubles may be caused by careless heat-treatment practice and some difficulties may be overcome by tightening up heat-treatment conditions, ensuring uniform furnace temperature, and going to the trouble to provide suitable quenching jigs. In the heat treatment of large tools and dies it is a common practice to place the components in a pre-heating furnace at a temperature below Ac_1 to ensure that it is heated right through. It is then transferred to the hardening furnace; the outside will naturally be heated faster than the centre and transformation will proceed from the outside to the middle, but the gradients and stresses will be much gentler than would be the case if a cold component had been put in a furnace at the hardening temperature. This practice is considered to heat the steel to the hardening temperature in the shortest time consistent with the avoidance of clinking, but it doubtless helps to counteract distortion also.

Other practical measures that assist in avoiding distortion are adequate support of all parts of the die in the furnace—to avoid sagging and creep of the steel at high temperature—and pre-heating of tongs and other handling tools—to avoid localized quenching effects.

Even when all precautions have been taken, the process of heat treatment involves changes in dimension which cannot be avoided. Nevertheless, efforts are made to reduce thermal and transformation stresses and overall dimensional changes to a minimum. A broader understanding of the mechanism of heat treatment has led to the development of quenching techniques that develop full hardness with less risk of distortion—to wit, marquenching or martempering—and prolonged studies of the effect of alloying elements on various properties of steel have led to the development of air-hardening and non-distorting steels.

Marquenching or martempering applies the benefits of progressive heating by means of a pre-heating furnace to the quenching process. Instead of quenching straight from the hardening furnace into water or oil, the component is quenched into a salt or lead bath at a temperature just above M_s (fig. 5) where the temperature is equalized before martensite transformation is allowed to occur on further cooling. This procedure will reduce internal stresses to a minimum, and resembles the pre-heating technique in this respect, but it will only develop the full hardness of the steel if no transformation occurs while the steel is held at the intermediate

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The history of die-forming

ERNST VON WEDEL

Although many great developments in the art of metallurgy have taken place in the 25 years' lifetime of this journal, it is as well to remind ourselves sometimes that many basic processes still in use today date from remote antiquity. An example of such a process is forming with the use of dies—the history of this process dates back over 2,500 years. The original paper, published in ' Stahl u. Eisen,' October, 1959, was given at the 15th session of the Historical Committee of the Verein Deutscher Eisenhüttenleute

NOWADAYS, the principal advantages of die-forming methods such as die-forging, deep-drawing, deep and shallow stamping (coining), compared with machining techniques, are seen in the possibilities of economical and rapid mass production. It is quite obvious that the preparation of a special punch or die for shaping metal has only been worth while, from the very beginning of the development of these methods, some 35 centuries ago, where a great number of identical articles was required. Owing to the short life of the dies, particularly when made of stone (which was used until about 700 years ago), however, the principal advantage of die-shaping compared with mould-casting, hand-beating (repoussé work) and free-hand forging was found especially in the high quality and dimensional accuracy of the surfaces produced. Thus, until some 500 years ago, this technique was used almost exclusively for producing ornaments, jewellery and coins.

It may seem surprising that this advantage of high-surface finish and accurate shaping had not been more widely used for making consumer goods. Until about A.D. 1200 this was probably due to the fact that, with manual operation, the necessary labour and power, as well as suitable materials, were not available.

The use of permanent moulds for plastic forming is already encountered in Stone Age pottery techniques. No proofs have survived from the age in which the first attempts at working virgin metals—in the Mediterranean area, about the fifth century B.C.—for the use of such moulds. In the fourth century B.C. crucible casting and the smelting of gold, silver and copper became known: in regard to the production of consumer goods, however, Stone Age conditions still persisted. Tools for embossing and decorating sheet metals were still made of stone. In the Mediterranean world the Bronze Age begins in about the third, and in Northern Europe the second, millennium B.C. Sulphide and arsenical ore metals and, finally, tin bronzes, enabled the production of the first efficient metal weapons and tools. Bronze stamps and punches are the first tools used in metal shaping; but, for the Bronze Age craftsmen, casting was still the most important technique.

Stone dies

The oldest known dies, found at Mycenae, are nearly contemporary with the first representations of bronze-casting and working, on the tomb of Rekh-mi-Rah, in Egypt, about 1500 B.C.; apart from the few wooden formers for the beating and drawing of metal vessels. Schliemann still considered these shallow die stones to be casting moulds. They are, however, too shallow to be fully charged with liquid metal, in consideration of the surface tension of precious metal melts. In addition, the same site provided workpieces of thin sheet gold, obviously made in these moulds. This is the first instance of a sheet metal-forming die. The sheet is hammered into the die, with the interposition of a coat of pitch or putty. This technique is used by goldsmiths up to the present day and has never been forgotten. Fig. 1 shows such a die stone, of close-grained red granite. It will be noticed that two such ornaments can be combined in a plane joint to form an imbricated pattern.

The thickness of the sheet metal worked in such stone dies varied according to the material, whether gold, silver or copper, between 4–16 thou. The depth of the impression is usually less. Since only very few tools have come to light, workpieces have been investigated for signs of the use of such die-embossing technique. In the museums far more articles from pre-Christian times are found with indications of hand-beating and punching tech-

1 *Granite moulding die*
(*H. Schliemann: 'Mykene,' Leipzig,* 1878, *Fig.* 162)

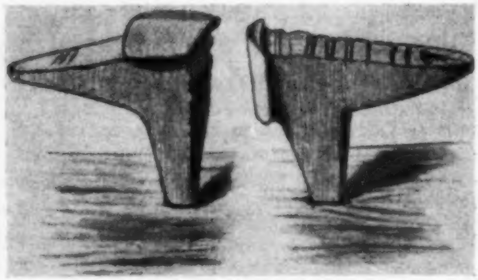
niques than pieces showing the use of a forming die. Great care is needed in assessing, since embossing techniques were very highly developed. Embossed work can only safely be assumed if a number of specimens, for instance, show the same faults in the die, or characteristic drawing folds or the like.

In the eighth century B.C., in addition to these stone moulds, the first bronze dies for sheet-metal embossing appear. They were obviously used for decorating sheet bronze articles. Their impressions are even shallower than those of the stone moulds for soft metals. They have generally been produced by pre-casting and after-chasing.

At least 300 years older are some small bronze anvils from Central Europe, bearing simple engraved designs. Fig. 2 shows a double-tang anvil found in France. This can be so fitted as to be used on the double-pane face or on the engraved face. This has obviously been used for cross-shaping bracelets, fibulas and the like. This is, consequently, a case of solid shaping and not of sheet moulding.

Early coining

In the Mediterranean area coining appears as



2 *Bronze double-tang anvil, about* 1000 *B.C.*
(*Evans: 'Bronze Implements,' p.* 182. *Original in Ashmolean Museum, Oxford*)

the first instance of the shaping of solid forms in or by means of dies. They are contemporaneous with the first bronze dies for sheet-metal shaping.

The first coins of electron metal still show on the reverse side the *quadratum incusum*, the square impression of the counterpunch; until, 200 years later, the first two-sided coins were produced.

For stamping such coins many blows with a hand hammer were necessary. Owing to the rebound of the hammer, the punch and the coin had to be reset after each blow. Many coins with a multiple impression witness even today to these difficulties: particularly during the first few blows, while the impression was not yet deep enough.

In about the sixth or seventh century progress was made with an inversion of the sheet-embossing technique into the stamping process: the intaglio, or recessed impression, being replaced by a relief-cut punch. The counter-die was again represented by pitch, end-grain wood, leather or the like. Some bronze cists from Hallstatt, in particular, show ornamentation on the upper and lower edges which, by its regularity, implies the use of some form of punching technique. Fig. 3 shows a bronze punch from the Mediterranean region with clearly visible hammer marks. Archaeologists had not hitherto been able to interpret these finds.

Die-stamping iron

The oldest occurrence of the die-stamping of iron is Sparta's iron coinage—about 500 B.C. There are no other indications of this in the Mediterranean area up to and including the era of the Roman emperors. In the north of Europe, on the other hand, the shaping of iron between dies appears to have been fairly common since the middle and later La Tene periods. A Teutonic sword sheath with a decoration in openwork relief from this period was hitherto considered, according to Kosiuma, as an evidence of die-forging; metallographic analysis has meanwhile shown, however, that this assumption was false and that the piece

3 *Bronze punch, Persia,* 700 *B.C.*
(*British Museum, London. Near-Asiatic Dept., No.* 128794)

has not been die-shaped. On the other hand, a piece from about A.D. 200, found in Sweden, hitherto thought to be an anvil, has been clearly identified as the upper half of a swaging die. Similar pieces from about the beginning of the Christian era have been found in Pompeii, in a blacksmith's workshop. The swaging die is encountered fairly frequently in Roman and Teutonic decorative art, particularly in connection with silverware, in and after the first century A.D.

One of the best examples of die-stamped ironwork so far discovered is an iron chape of Celtic workmanship, found in Austria. It shows the obvious influence of coining technique, taken over by the Celts from the Mediterranean peoples in about the third century B.C. Up to the present nobody seems to have interested themselves in the manner of its production. Fortunately, since two exactly similar specimens were found, identification as die-shaped work was possible: on a single piece this would not have been the case.

Up to about 300 B.C., consequently, the identified methods of sheet-metal working by dies include die-embossing and its reverse form, die-punching; of solid metal working, shaping in engraver dies, coining and ornamental die-forging, and swaging in dies. In the latter case top and bottom dies are already in use, but the punches are still manually guided.

As already mentioned, owing to double-stamping this leads frequently, particularly in coining, to blurred impressions. This led to the development of stamping with rigidly-guided dies. Table 1 shows the development of hand stamping up to the fall of the Roman Empire. Firstly, hand stamping with bottom die and counter-punch, about 700 B.C., then stamping with top and bottom dies. The first attempt to simplify the readjusting of the dies after each blow is found in the Ptolemaic era, pairs of dies with centring pins having been used about 300 B.C. This impaired the quality of the coin impression, however, by the presence of the central pin mark, and the method appears to have been

	Features	First known use
(a)	Bottom die for one-sided impression. Reverse shows 'quadratum incusum,' mark of the punch with end engraving, struck several times in different places	7th century B.C., Lydia and Aegina
(b)	Top and bottom dies engraved. Impression still much smaller than face of coin	Greece, 6th century B.C. onwards
(c)	Coining dies with centring point for easier readjustment (only rotation needed)	Since about 300 B.C. Early Ptolemaic
(d)	Punch guided by cylindrical pin and socket	2-3 century A.D. Gallo-Roman (Serignan, Vaucluse)
(e)	Toggle guide	4th century A.D. Gallo-Roman (period of Emperor Constance I)
(f)	Rectangular of box guide. Guiding collar fixed on one die, or loose, as third component	Probably 2nd century B.C. Gallo-Roman. Latest A.D. 875, Anglo-Saxon

TABLE 1 *Coin stamping by hand*

abandoned. The next three methods originated in France, in the Roman imperial era, and are therefore Celtic in origin. In the first the top punch is guided in the bottom die by a cylindrical pin. A double impression was still possible, by twisting the pin. Next was a toggle guide between top and bottom dies, and finally, a rigidly-guided, irrotatable pair of dies—used in coining the *aurei* of Faustina the Younger. This last design, in particular, shows a noteworthy advance in the state of the art, particularly in regard to 'tooling.'

Examination of series of ancient coins has shown that, in the Roman Empire at least, many coins must have been stamped in rigidly-guided dies. This knowledge then appears to have been forgotten everywhere and only begins to reappear more frequently towards the end of the Middle Ages. The swaging die, on the other hand, remains in use, as evidenced by the Tjele finds and the description by Theophilus of the *organarium*.

Influence of Islam world

The level of scientific knowledge and the practical arts at about the turn of the first millennium A.D. was considerably higher in the Near East, following on the triumphant advance of Islam, than in the West. Hence, at this period, knowledge-hungry young Europeans increasingly came to study at the Moorish universities in Spain. Much of this knowledge also reached Europe owing to the Crusades, particularly in regard to steelmaking processes. This explains, for instance, the sudden appearance of openwork iron ornaments and trellis-work, forged in a one-part die, in Germany, England and France, about the year A.D. 1250, probably attributable to Arabic influence.

Fig. 4 shows such tracery, rosettes and foliage, forged in a one-part anvil die and welded into the trellis-work. The reverse side is flat. Since the opening of the Gothic period this technique gave the impulse to a wide use of ornamental ironwork. At this time stone dies and swages again make a transient appearance in France, for sheet-metal embossing, instead of the usual moulds and patterns of metal. This period also saw the introduction of water power for operating the forge bellows, and later also the hammers. Water-power hammers were, however, at first only used in the primary working of the metals; while the further working was still done entirely manually in the craftsmen's workshops. Only when the invention of gunpowder started the rearmament of the knightly armies did such hammers come to be used occasionally for forging cannon balls in swage dies. However, already at the beginning of the 16th century cast shot had replaced the forged product; only bullets for small arms were still forged in dies until lead came into use for the purpose.

4 *Trellis-work decoration of die-forged components, about A.D.* 1250

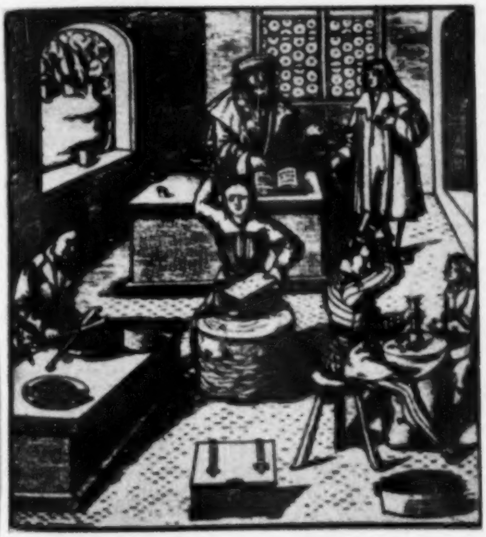
(Musée de Cluny, Paris)

Craft guilds

About the year 1200 craft guilds made their appearance, the movement being particularly promoted by the wanderings of journeymen to Italy. In most towns this led to extreme specialization and monopolization of the individual crafts. Thus the metal workers were in some towns divided among no less than 30 guilds. In view of such specialization of their products these craftsmen naturally often used dies—*e.g.* the bell-makers and thimble-makers in Jost Amman's Book of Estates.

Essentially, however, both the later Middle Ages and the Renaissance were anything but 'die-minded.' Individualism and craft pride led to individual production and guilds and corporations issued savage edicts against overproduction. Not surprisingly, therefore, labour-saving machines and methods were suppressed and hardly in evidence. In Italy the city states were slightly more far-seeing: they protected and promoted inventions and improvements.

It was only in such surroundings that a man like Leonardo da Vinci could towards the end of the 15th century develop his suggestions and examples of the many new pioneer machines and appliances which we find mentioned in his works. In the



5 *A mint shop, about A.D.* 1500
(*E. Mummenhoff: 'Das Handwerk,' Jena*, 1924, *Fig.* 28)

field of die-shaping we find him the first since antiquity to suggest a rigidly-guided coining die assembly; which, evidently, did not find favour, as an inspection of Italian coins of that period will show. The screw press—originally only a wine and oil press—was first used for coining lead seals in the 15th century by Bramante, and somewhat later, by Benvenuto Cellini, for coining medals. Cellini, in any case, applied the potential dynamic energy of fly-weights, whereas until then only the static energy of the press spindle had been employed.

The first step towards mechanized production in the shaping of metals was provided by the great Paris mint reconstruction of 1552. Until then coins were generally stamped in the manner shown in Fig. 5. The man in the centre is beating out the metal with a hammer. The man on the left is shearing the blanks; on the right coining is being done with a manually-guided top die or punch. The mint master in the background is gauging the coins with the help of the scales. Such coins were neither truly round nor true in weight, encouraging clipping and counterfeiting.

By order of the king, in the year 1552, a set of machines was installed for coining devised by a goldsmith from Augsburg. In these the metal was no longer beaten, but rolled and passed through a gauge. The blanks were punched out in a press. They were thus already gauged before coining. It was originally assumed that the coining was done in a screw press, the so-called fly-press. Later, further indications led to the conclusion that the first machine used in Paris was of the drop-hammer type.

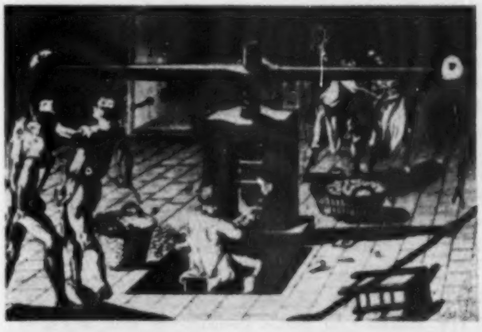
Also in the 16th century the Archduke Sigismund introduced roll-coining, at Hall in the Tyrol. Gauged strips of metal were run through a pair of rolls with an oval engraved impression. The coins were then punched out of the strip. They were always slightly concave and, contrary to the Parisian individual coining method, could not be edge-coined or milled. A later development was the repeater press, in which single dies rotated on the roll spindles. This machine only came into general use in Spain and Austria.

Not later than at the end of the 17th century all coining in Europe was being done in large fly-presses, such as shown in Fig. 6. In spite of a highly rigid press-frame and a double-threaded spindle, efficiency was low and the press far inferior to the drop hammer. The output per man was about 6 ft.-lb., while with the manual drop hammer about 9 ft.-lb. and the stirrup drop hammer about 15 ft.-lb. were attained—as calculated by Coulomb towards the end of the 18th century. Hence, in private enterprise manufacturing, the drop hammer replaced the screw press about the end of the 17th century. From this time proofs are available that the foot-operated drop hammer was in use by the pin-makers of southern Germany and the button and buckle makers in England.

The solid shaping of steel—particularly for components of firearms in state ordnance factories—was, however, performed right up to the end of the 18th century, principally by means of a set and set hammer, and sledge, on an anvil.

Rise of industrialization

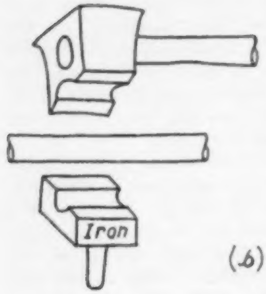
Christopher Polhem, the prominent Swedish engineer, was demonstrably the first to use a drop



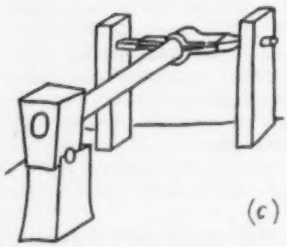
6 *Screw press of about A.D.* 1700
('*Encyclopedie methodique,' Paris*, 1760. '*L'art du serrurier*')

Swages and sets for shaping cross-sections (uniform cross-section over whole length)

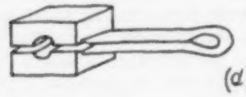
(a) End of 2nd century B.C. Bronze Age, north of the Mediterranean. Used as a swage and for other cross-sectional shaping



(b) About A.D. 1 (Pompeii). Round tang, no set hammer used

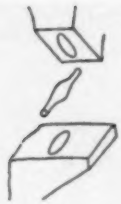


(c) Swaging die on tilt halve. Also for cross-sectional shaping of unround bars and strip. About 1700, Polhem, Stjernsund

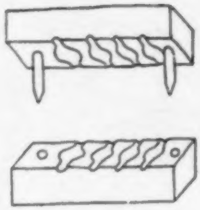


(d) Swage block for longitudinal and transverse shaping. Beginning of 18th century

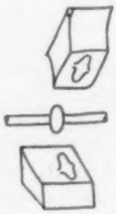
Swages and sets for longitudinal shaping (along the bar)



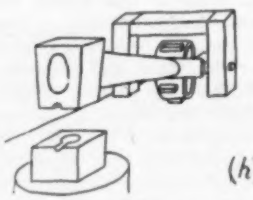
(e) End of 2nd century B.C. Swage for bead wire



(f) Multiple swage block, probably already known in Roman times. Reconstruction after Theophilus Presbyter (about A.D. 980)



(g) Top die of swage block. Bottom not available. Late La Tene period (1st century B.C.), Jattened, Wester-Gothland



(h) Cannon-ball forging by a water-driven tilt hammer. Reconstruction after Biringuceis and Nuremberg muniments

TABLE 2 *Solid shaping in swages and open sets, for cross-working strip and bar stock*

hammer for large articles, at his factory in Stzernsund in the year 1729. This hammer, as well as the dies from Stzernsund which are now in the Technical Museum at Stockholm, was most probably used for the manufacture of household utensils. In his political testament Polhem urgently recommended his countrymen to develop the use of die-forging, as the most important means of developing the natural resources of their country —in the form of ores and charcoal—in the direction of an increasing export of manufactured goods.

From the end of the 17th century England developed as the foremost manufacturing country in the world. In metal production and working, and the construction of machines and tools, it had far overtaken the war-torn continent of Europe. As in ancient Greece, about 500 B.C., the construction and maintenance of large war fleets gave a powerful stimulus to technical development. An extensive manufacturing industry in the hands of private enterprise operated with the most economical means and methods. Many patents of this period refer to die-shaping under the drop hammer and the fly-press, particularly in the Birmingham region. Boulton, Watt's partner, registered the first mechanical drive for a screw press. The hydraulic press invented by Joseph Bramah towards the end of the century was soon put into use for coining and die-pressing. Cutting tools for trimming and sockets for die-making were already known.

In France endeavours were being made to secure the interchangeability of gun parts by the use of

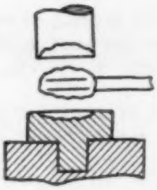
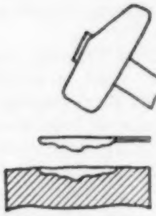
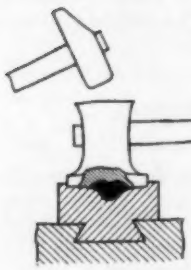
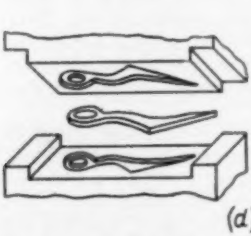
	Features	First known use
 (a)	Coining method for surfaces of solid iron ornaments. Probably influenced by minting practice. Dies do not come in contact in end position	La Tene period (300–100 B.C.), Ratzersdorf, Austria
 (b)	Drop forging in one-sided die. Top of the work-piece beaten flat by a hammer or with a flat-faced set. Set surfaces in contact in end position	Since about A.D. 1250 in more frequent use in Europe; presumably of Arabic origin
 (c)	Closed die. Set and bottom die recessed. Tenon for bottom die in anvil. Die made by inserting hardened master pattern between the hot set and the bottom die	Used in ironworks latest from the beginning of the 18th century
 (d)	Drop forging a pre-cut blank (scissors half). Both dies recessed; upper die carried on the tup of a drop hammer	Reconstruction after British Patent 1507 of November 24, 1785. Elements of the method known in England, probably from beginning of 18th century

TABLE 3 *Drop forging*

die-forging. The rapid developing of cutting techniques—until then very much in the background compared with the casting and forging of steel—led to the development of copy-milling. It is quite right to say that, by the end of the 18th century, most of the mechanical elements of drop- and die-forging as we now know them had already been developed.

Table 2 shows once more the development of the equipment for cross-sectional shaping of bar and strip stock since the Bronze Age: the simple anvil engravings of about 1000 B.C., the swage blocks of the La Tene period, the multiple swages described by Theophilus Presbyter in about A.D. 1000, the tilt hammer for forging cannon balls about A.D. 1500, Polhem's tilt-hammer arrangement for forging rods, and the squeezer, still in use, about 1700.

Table 3 shows the process of drop forging in a closed die: the iron-coining process of the La Tene period; the ornamental forging in a one-piece die of the Gothic; forging gun-lock parts in an anvil set with a setting hammer about 1700; and a scissors-blade die for drop forging, according to an English patent of 1785.

Historical factors

An ideological study of the history of the above development brings out the following points:

A most important conception, by no means self-evident, is that of the press-shaping of sheet metal. The use of a yielding backing is appearing again, in the most modern forms of sheet-metal working: rubber-bag drawing, hydro-forming, the Mar-form process, etc. Adaptation to user needs coupled with an artistic striving after unity of form will have been the starting points of this development in antique times, and a deep understanding of the nature and properties of the material is also in evidence.

The influence which the art of coining has exerted on the cultural and economic development of the Mediterranean world is inestimable. Metal coinage in the form of bars existed previously. It was only when the coined impression guaranteed value and offered security against counterfeiting that metal became a means of commercial exchange between trading peoples. The adoption of means for controlled and constrained guiding of the coining punches may also be interpreted in this sense, as aiming at the prevention of counterfeiting and imitation and not constituting in themselves a deliberate step towards technical efficiency.

Mention must also be made of the deep depression experienced by the applied arts in the period between the Great Migration of Peoples and the Crusades. This very forcibly contradicts the doctrine of continuity of technical development. The fact that it was the Crusades which reintroduced the West to the heritage of the ancients, the Aristotelian philosophy, the natural sciences and the technical refinements of the Arabians, appears an historical paradox; it was in any case an unintentional development on the part of its initiators. The fact remains that Venice, for instance, owes its economic and technical prosperity precisely to its constant contact with the oriental world.

Historically unique is the ideological transformation of handicrafts into guild economy, towards the

end of the Middle Ages. Guild opposition to tools and machinery quite naturally culminated in the strivings after originality and individuality of the period of the Renaissance. That history never repeats itself exactly is seen, for instance, in the fact that the 'rebirth of antiquity' by no means completely reproduces the pre-Christian attitude towards the applied arts. Plato's contempt of the 'technician' is never fully resurrected.* Consumer adaptation and the division of labour in production also appear only later, towards the end of the 17th century.

The introduction of machines in the Paris mint and the introduction of roll coining in the Tyrol coincide temporally with the Renaissance, but, as measures of state policy, appear rather as the forerunners of subsequent mercantilism and cameralistic economics.

The breaking of guild supremacy, the introduction of patent laws and the publication of the first technical reference books were means adopted by many states since the beginning of the 17th century to foster the development of the useful arts and crafts. The ideologies of the Age of Enlightenment and Liberalism promoted the rise of manufacturing and introduced the Industrial Age.

It is of some importance to note that it was the introduction of die-forging in state armouries and ordnance factories, and of coining presses in the mints, long before the introduction of spinning and weaving machinery, which gave rise to the first workers' strikes and machine-breaking riots, later to become so disastrously frequent. The technical features of these developments had, however, long been known and been used without any disrupting effect on the social structure.

Conclusions

The shaping of metals in dies is by no means an invention of the technical age, as has often been assumed. Sheets of the precious metals were shaped or embossed in single stone dies, with the help of a yielding backing of pitch or bitumen, already in 1500 B.C. The stamping of coins since about 700 B.C., simple anvil shaping of cross-sections (bars) in the Bronze Age of northern culture, the stamping of ornaments during the La Tene period in Germany, using wrought steel, the swaging die in Roman and Early Teutonic times, and improvements in the guiding of stamps and punches for coining in the Roman Empire are the oldest known progenitors of modern die-stamping and drop forging.

The forging of lattice-work ornaments in single anvil sets during the Gothic Age obviously stems from Oriental influences.

Since the 15th century screw presses are found in use for stamping coins and medals. At the middle of the 16th century mechanical coining of previously gauged blanks and coining between engraved rollers become usual.

In the 16th century the drop hammer comes into use for small articles of mass production. From the 18th century onwards drop forging becomes common for the production of firearm components; at the same time, it is introduced in England and Sweden for the manufacture of a variety of consumer goods.

The development of this technique through three millenniums not seldom shows interesting parallels and associations with the general historical events of the period in question.

*Plato's contempt for the technician was by no means the universal attitude of pre-Christian societies. In fact, the master craftsman was respected in the ancient Egyptian civilization, and in more primitive communities the metal worker was often closely identified with the priest-magician as possessing knowledge essential to the well-being and prestige of the tribe. A survival of this attitude was still to be met in early medieval Europe in the legends of the forging of miraculous swords and armour.—EDITOR.

Effect of carbide stringers

continued from page 400

temperature. That depends on the time-temperature-transformation characteristics of the steel, which are a function, primarily, of its composition. Clearly, the heavier the die, the longer it has to be held in the salt or lead bath to ensure a uniform temperature distribution and the lower must be the tendency of the steel to transform at this intermediate temperature. This means that for heavier sections it is necessary to use steels of higher hardenability, in practice steels of higher alloy content.

Further refinements of heat-treatment technique are likely to take the direction of modifying the properties of quenching media so that the cooling curve in a continuous quench comes closer to a marquenching treatment. The use of alginates and other additives in water already makes it possible to select a wider range of quenching rates between water and oil. Further development along this line, or the analogous modification of oil by suitable additives, may extend this range to slower rates. The introduction of discontinuities in the cooling curve will be more difficult to achieve, but may not be impossible. A possibility that may be worth serious study is the use of 'fluidized beds'[7] as quenching media; by utilizing the thermal effects of phase changes in the solid medium, changes in cooling rate at critical temperatures may be attained without operational modifications.

to be continued

The electron microscope

Some applications to the study of aluminium

DR. HEINZ BICHSEL

This article, which appeared in 'Aluminium Suisse,' May, 1960, No. 3, relates to work carried out at the Aluminium-Industrie-Aktien-Gesellschaft Research Institute at Neuhausen am Rheinfall, Switzerland. It shows in simple outline the potentialities of electron microscopy in metallurgy with the aid of examples taken from studies of aluminium. Electron microscopy was just being born when the first issues of 'Metal Treatment' appeared 25 years ago; the amount of space devoted to the subject in these pages today is an indication of the increasing part it now plays in metallurgical investigation

THE THEORY OF IMAGES of Abbe (1840–1905) shows that the capacity of the optical microscope is limited. The wavelength of light determines that the maximum attainable linear magnification is only 1,500 times, while it is possible to raise the power of resolution under the most favourable conditions to $0{\cdot}2\mu$, which corresponds to 2,000 Å (1 Å $= 10^{-8}$ cm.). By the power of resolution d of a microscope we understand the ability to distinguish two neighbouring points separated from each other by a distance d.

Abbe himself had arrived at the conclusion that it was theoretically possible to increase the power of resolution, but by striking out along completely new paths. Although in the second half of the last century the 'light source' of the electron microscope, namely, cathode rays, was already known, as well as their refraction in magnetic and electric fields, people were still far from the idea of a microscope based on cathode rays. The reason was, perhaps, that electron radiation was first of all studied from the aspect of 'matter,' that is to say, it was considered to be corpuscular radiation.

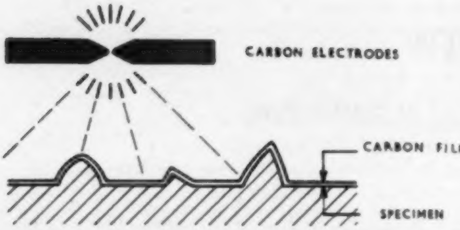
Presenting his fundamental equation $\lambda = h/m.v.$ in 1924, de Broglie linked the corpuscular and undulatory nature of matter. After his theory had been confirmed during subsequent years through diffraction experiments, two groups of research workers, namely, Ruska and v. Borries and Ramsauer and Brüche, applied themselves to the development of electron radiation optics. In 1930–31 the first of these research workers constructed an electron microscope equipped with electro-magnetic lenses, while at the same time the others built an instrument with electrostatic lenses. Today, to a large extent, there are available excellent electron microscopes of very varied origin. The best instruments have a power of resolution better than 10 Å.

In a normal electron microscope the beam of electrons passes through the object; this object must then necessarily be very thin in order to utilize fully the power of resolution. For the examination of metals the preparation of the specimens can be conducted principally in two ways. An exceptionally thin metal foil which permits the transmission of the electron beams can be used as the object, or a replica of the surface to be investigated can be produced. The method of thin foils, only developed in the course of the last ten years, has shown very promising results and will be described below in greater detail.

Carbon replicas

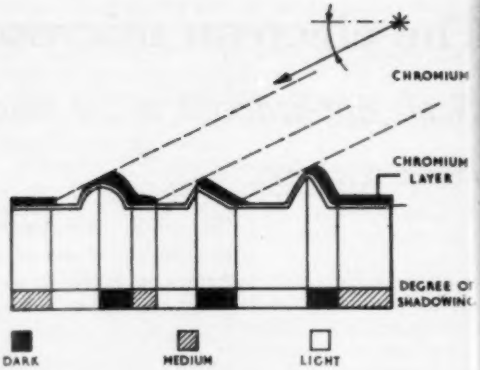
The simple method of carbon replicas is very well suited to the study of metal surfaces (fig. 1). In a high vacuum pressure of 10^{-4} mm. Hg a carbon film about 500 Å thick is evaporated on to the polished and etched surface. After immersion of the specimen into a bath of mixed acids, the carbon film which reproduces the topography of the surface of the specimen is thereby released. Small fragments of this film are collected on to carrier grids and dried.

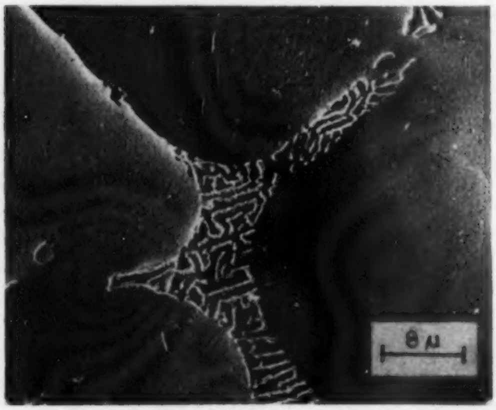
In order to increase the contrast the replica can be shadowed with chromium at a definite angle, generally at 30°. As may be seen from fig. 1 (*b*), the thickness of the vaporized chromium layer is dependent on the local inclination of the carbon film. On the reverse side of elevations no chromium is deposited, while on the side turned towards the source of shadowing on the other hand much chromium is deposited. During radiation these layers of chromium of differing thicknesses influence



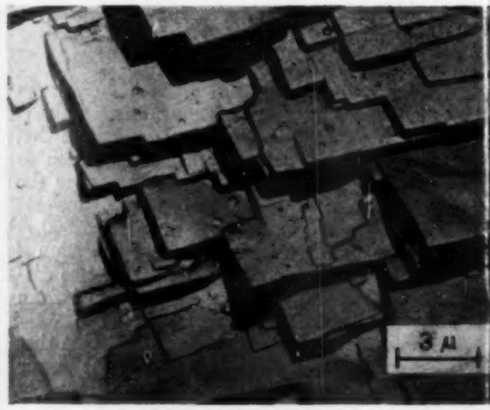
1a (ABOVE) *Production of surface replica by means of a film of evaporated carbon* (500 Å *thick*). *The carbon electrodes strike an arc in a vacuum of* 10^{-4} *mm. Hg*

1b (RIGHT) *Oblique shadowing with chromium in vacuo,* 10^{-4} *mm. Hg after releasing the carbon film* (*electrolytically by means of acids or organic solvents*) *from the surface*





2 *Structure of continuously cast pure aluminium. AlFeSi component* (*carbon replica shadowed with chromium*)



3 *Etching attack on pure aluminium. The cubic structure of the aluminium is revealed by the attack of the acids.* (*Oxide replica*)

the intensity of the electron beam and thereby the brightness of the image. At a given angle of shadowing it is in addition very easy to measure the height of the elevations from the length of their shadows.

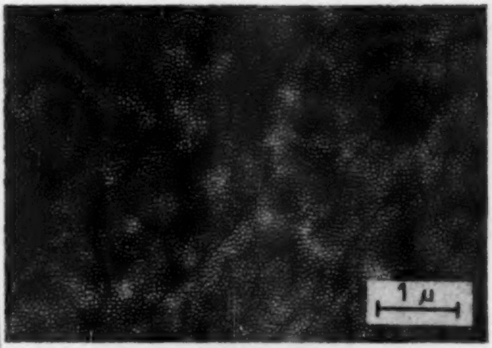
Fig. 2 shows a eutectic precipitation along the grain boundaries in continuously cast pure aluminium. Here we have a ternary, intermetallic compound of aluminium and the natural impurities, iron and silicon, which is described in literature as 'Chinese writing.' The plastic effect is produced by the oblique shadowing with chromium.

Oxide replicas

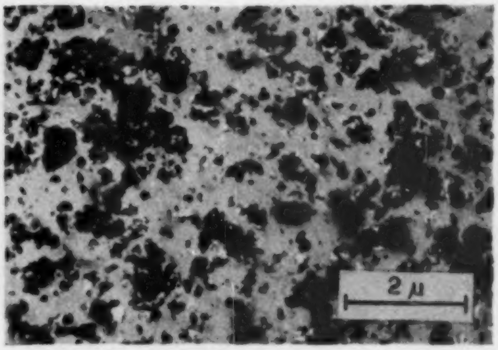
Apart from the production of carbon replicas there are further methods of producing images of surfaces. Here brief mention should be made of oxide replicas which are important for aluminium. On the chemically or electrolytically polished surface, a structureless and non-porous oxide film of about 500 Å in thickness is produced by means of anodic oxidation. The thickness of the layer is proportional to the voltage applied to the bath. The thin films may be isolated by immersion of the aluminium specimen in a sublimate solution.

As an example of an oxide replica, fig. 3 shows the breakdown of the surface of pure aluminium caused by etching. The acid mixture used attacks the metal in such a way that the surfaces of the cubes are revealed.

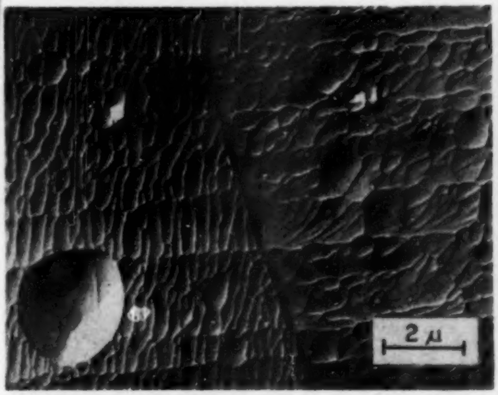
The oxide replica method can also be used directly for the investigation of anodically produced oxide films. According to the conditions of oxida-



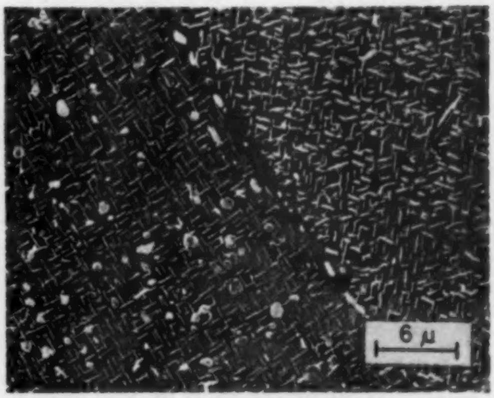
4 Structure of an oxide film produced on aluminium by anodic oxidation in 20% sulphuric acid. The porosity is clearly recognizable. (Direct transmission of the isolated oxide film, about 500 Å thick)



5 Oxide replica of an electrolytically polished S.A.P.-895 foil (oxide-containing, sintered aluminium). Ths illustration shows the distribution, shape and size of the oxide particles



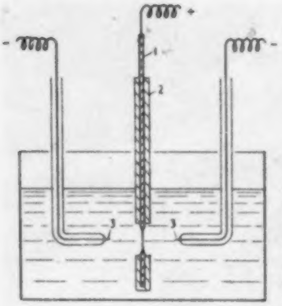
6 Honeycomb surface structure on chemically polished Raffinal. Grain boundary running obliquely across the micrograph. (Oxide replica)



7 Structure of an aluminium alloy containing 4% Cu. Quenched and tempered at 300°C. Two grains with differing orientation, which contain copper aluminide precipitates in different arrangements. (Carbon replica)

tion and the composition of the electrolyte the film shows a different structure. Here, also, for investigation in the electron microscope the film must be very thin, *i.e.* about 100 times thinner than the oxide film used for technical purposes. For a long time already it had been considered probable, on the basis of electrical measurements, that pores were present in the oxide film. It was only the electron microscope, however, which produced direct evidence. Fig. 4 shows an oxide film produced in a bath of sulphuric acid with a voltage of 19 volts. The average diameter of the pores is about 250 Å. Before anodic oxidation the specimen was chemically polished in an Alupol bath. The unique structure of the lines is a surface structure produced by the polishing bath, which is portrayed in the oxide film.

During the investigation of S.A.P., which is an oxide containing sintered aluminium material with high heat resistance, the oxide replica method proved very satisfactory. Not only was the topography of the surface reproduced, but the fine oxide particles of the S.A.P. are intimately included into the anodically produced oxide film during oxidation. Thus we obtain a good picture of the orientation, size and distribution of these particles. As the initial material for fig. 5 an S.A.P.-895 foil was used, which explains why the majority of the oxide flakelets are oriented parallel to the surface of the specimen.



8 Bollmann apparatus for the production of thin metal specimens suitable for transmission electron microscopy.
1, Aluminium foil.
2, Resin coating.
3, Pt electrodes

9 Raffinal foil annealed for 24 hours at 200°C. with subgrains with varying degrees of growth. (Transmission micrograph)

Through the chemical polishing process the aluminium surface acquires a characteristic, submicroscopic structure. Fig. 6 shows a Raffinal surface treated in a phosphoric acid-nitric acid polishing bath. Through the polishing bath all the irregularities of the surface are levelled out, and a cell structure is formed. The cells, bounded by a network of rib-like elevations, are like flat furrows in contrast to normal etch pits, which is likewise the reason for the high polish of the surface. The nature of the cell structure is formed somewhat differently on either side of the grain boundary running almost vertically.

A very fine carbon replica of a structure is shown in fig. 7. Here we have an aluminium alloy containing 4% copper, of the Avional type, in which the copper is precipitated out of the solid solution as a result of annealing at 300°C. A grain boundary with a zone free of segregates may be recognized running diagonally. The phase containing copper precipitates during high-temperature hardening in platelets parallel to the cube planes of the aluminium lattice, which in accordance with the space directions shows three parallel groupings of platelets. Dependent upon the plane in which the crystal is cut, a special arrangement of the θ′ platelets is produced. θ′ is the metallurgical designation of this aluminium-copper component.

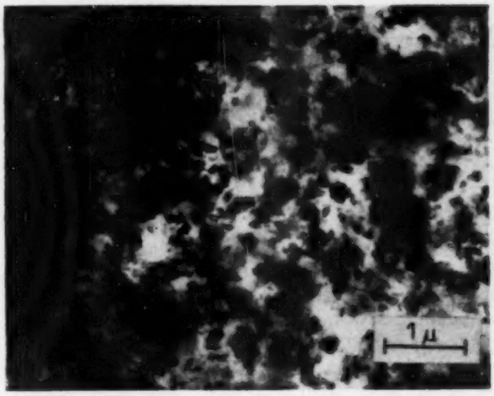
The grain in the left part of fig. 7 possesses a cube face in the polishing plane. Two groups of platelets were cut diametrically and therefore appear as rods, whereas the third group lies directly in the plane of the polished specimen. The grain on the right shows a more usual position, and the precipitates are arranged parallel to the three space directions. The higher the temperature, at which the specimens were precipitated after the completion of solution annealing and quenching, the longer will be the precipitates. After hardening at 160°C. the specimen shows a considerable increase in hardness; the precipitates are extremely fine, and as experience shows, can no longer be clearly reproduced by the replica technique.

Thin metal foils

Whereas during observation with the optical microscope the individual phases may be identified after suitable etching by means of colour effects, with the use of the replica technique for electron microscopy one has recourse only to the formation of the surface relief. Here the purpose of the etching lies in the production of a relief capable of affording as much information as possible. Unfortunately it is not possible in all instances. Difficulties are caused primarily by alloying components which are less noble than aluminium and which are dissolved out during etching. Moreover, sub-microscopic precipitates, above all if they are coherent with the aluminium lattice, cannot be revealed. In these instances the transmission method, already mentioned, must be used.

For the production of thin metal foil specimens of a thickness $<0 \cdot 1 \mu$ there are various methods. That of W. Bollmann is frequently used (fig. 8) The thin metal specimen which is connected as the anode is placed in circuit between two platinum cathodes, and a polishing bath suitable for aluminium is used as the electrolyte. In the vicinity of the platinum electrodes the metal is very evenly reduced and a flat surface is left. As soon as a hole is formed, the treatment is broken off. Certain areas around the edge of the hole are very thin and suitable for transmission electron microscopy.

In recent years this technique has produced a



10 *S.A.P.-895 foil containing about 10% oxide. Oxide particles (dark) and lattice defects (short dark lines). (Transmission micrograph)*

11 *1 mm. Avional-25 sheet, quenched and tempered. Copper aluminide and magnesium silicide precipitates in the grain boundaries and in the centre of the grain respectively. (Transmission micrograph)*

whole host of fundamentally new results. In this way, apart from the submicroscopic alloying components, the grain and subgrain structures may also be made visible. This permits a thorough study of the recrystallization process. Lattice faults in the metal crystal, which hitherto could only be indicated by means of improved X-ray methods, can be directly observed by means of the transmission technique. Although this line of research, as already mentioned, is relatively novel, a large number of fundamental studies on the subject already exist.*

Some examples will be given to characterize this new investigation technique. Fig. 9 shows the subgrain structure of a Raffinal foil after 24 hours' annealing at 200°C. The foil is only partially recrystallized. Apart from the small subgrains of 2–4μ dia., grains about 5–10 times larger are visible. These already belong to the primary, recrystallized structure. Subgrains form in worked metal, and are to a certain extent a preliminary step during the breakdown of lattice distortions. They grow even during annealing at temperatures below the recrystallization temperature.

If roll-hardened Raffinal foil is annealed at various temperatures between 20 and about 250°C., the growth of the subgrains with rising temperature can be very readily observed.

A transmission micrograph of S.A.P. is shown in fig. 10. Here we have the same initial material which was also used in fig. 5. On comparing the two illustrations the different density of the oxide flakelets is striking. This may be explained by the fact that the metal foil is thicker than the oxide replica, and the oxide particles are simultaneously visible from all the regions lying at various depths. The shape of the oxide particles is, however, the same in both micrographs. The transmission method in addition shows further interesting details, such as dislocations (lattice defects), for instance, which appear as dark lines. A metal will work the more easily, the more mobile are the dislocations. But in a material like S.A.P., with a very finely dispersed secondary phase, the dislocations are impeded in their mobility, or even completely blocked on the boundary surfaces between the metal and the foreign particles (oxides). The high heat-resistance of S.A.P. in all probability lies in the restriction of the mobility of the lattice imperfections.

Fig. 11 shows the transmission micrograph of an aluminium alloy. The initial material, a 1-mm. Avional-25 sheet, in the fully quenched and tempered state, was thinned down by means of a special technique, in order to obtain specimens suitable for transmission electron microscopy. Along the three grain boundaries may be recognized precipitates of copper aluminide, 0·4–0·8μ in length. The interior of the grain contains the submicroscopic precipitates which originated from the supersaturated solid solution during the thermal ageing process. The Guinier-Preston zones (G.P.[2]) containing copper appear as small parallel rods, and are often surrounded by a light fringe (fig. 11, bottom left). The G.P.[2] zones, also called the θ″ phase, have the form of platelets like the θ′ phase (fig. 7), and are arranged at right angles to the cube planes of the aluminium lattice. In contrast to the θ′ phase, which may in fact be

continued on page 414

* Most of these publications are by British authors.—EDITOR

Stainless steel in architecture

concluded from page 394

as valid to its epoch as its classical predecessors were to theirs. The structure of Paxton's great building was composed of cast-iron members delicately sheathed in glass, a diaphanous membrane revealing a new aesthetic inherent in the industrial process.

But the early structures using cast iron, steel or reinforced concrete were either an engineering *tour de force*—sometimes quite daring and beautiful—or were ignominious props supporting a façade of classical forms; a mask of applied ' styles ' selected to conform to what was fashionable at the moment. The architect was but a cosmetician. Not until 1883, in Chicago, Illinois, was there positive evidence of an original, creative architecture resulting from the new technology. Twelve years previously the city had been decimated by a great fire and in its reconstruction the demands of expediency far overshadowed the more fundamental needs of an architectural and planning order.

Into this chaos came a small group of architects and engineers. They were the first to comprehend the architectural potential of technology and, although their work was but the germ of an idea and had to wait almost five decades for full fruition, it constituted a movement of such importance as to affect architecture the world over. The work of these great innovators became known as the Chicago School, and Jenney's invention of the steel frame in his Home Insurance Building in 1883 became known as ' Chicago construction.'

But America was not then mature enough to accept or recognize an original, honest architecture. It was readily seduced by the return of the classical façadism of the Columbian Exposition of 1893 in Chicago. The lessons of the Chicago School architects were negated in a world of historical revivalism and, except in the genius of Frank Lloyd Wright, the truths of Jenney, Root and Sullivan were all but lost.

Not until 1939 in the work of Mies van der Rohe do we find an architecture which projects the development implied in the work of these early pioneers. In Mies' first structure in America, the Metals and Minerals Research Building at the Illinois Institute of Technology, 1941, there is a return to the consideration of structure as an architectural factor. Here we see the true meaning of the curtain wall as it is related to the primary structure of the building.

The idea of the curtain wall was born in 1883, but not for some 50 years did its expression begin to reflect the technology of its time in thin, lightweight sheathings of glass and metals, and only since 1946 has metal curtain wall had a widespread commercial application in America.

The engineer and manufacturer were giving the architect more new means than he could keep pace with, although they must not be accused of providing the architect with an overabundance. Neither must the architect be considered entirely remiss in his duties if he failed to immediately assimilate the wealth of new materials, and new techniques, for it is not an easy matter to keep pace with today's rapidly moving technology. We must bear in mind that new materials, new techniques and the consequent new forms have a meaning only in relation to what we make of them.

It is inevitable, therefore, that in the development of metal curtain wall faults and failures have occurred along with successes. And now, beyond the mechanics of the problem, we have only recently been alerted by the architectural press to the danger of curtain wall becoming aesthetically monotonous; in many instances undoubtedly a valid criticism, but further advances in curtain wall technology and their absorption by those involved with it will, I believe, permit latitude in developing designs which will not result in the unfortunate consequences of doing curtain wall the easy way.

Electron microscope

concluded from page 413

considered as a precipitate, the θ'' phase is intimately included in the host lattice, and shows on the other hand a slightly smaller lattice parameter than that of aluminium. This brings about a contraction of the aluminium lattice in the direction of the normals of the platelets. This contraction, which gives rise to the light diffraction fringe on the edges of the θ'' platelets, is the cause of the increase in the mechanical strength, through the addition of copper. In the larger of the small rods in the centre of the grain, which are oriented more or less at random, we have crystallites of magnesium silicide. All these fine precipitates are beyond the power of resolution of the optical microscope.

The production of specimens for electron microscopy, be it by means of replica methods or through electrolytic thinning of metal specimens, is relatively difficult and requires much experience. Nevertheless, as the examples given show, the electron microscope greatly assists research into the metallography of aluminium. This valuable instrument is to a large extent capable of explaining certain connections between the properties of the metal and the state of its microscopic structure, which is below the resolution of the optical microscope.

Technical developments in modern drop stamps and forging presses

J. S. BYAM-GROUNDS

This article on the basic factors which qualify the design of drop hammers and forging presses is based on the paper given by the author at the 1960 Spring Lectures of the National Association of Drop Forgers and Stampers. The first part of the article given this month deals with the drop hammer and will be concluded in the next issue with a discussion of forging presses. Mr. Byam-Grounds is deputy managing director of B. & S. Massey Ltd.

THERE ARE certain fundamental elements around which any drop hammer or press must be designed and the difference between the various makes of plant is rather one of emphasis. Excepting special-purpose machines, nearly all designs are a compromise, the equating of a number of factors to suit the differing needs of a variety of customers, with sufficient standardization to manufacture and sell at a competitive cost. It is these basic elements of the drop hammer and forging press on which a variety of design forms may be based, and their relation to one another, which I shall attempt to define in this paper.

Factors which govern the drop hammer

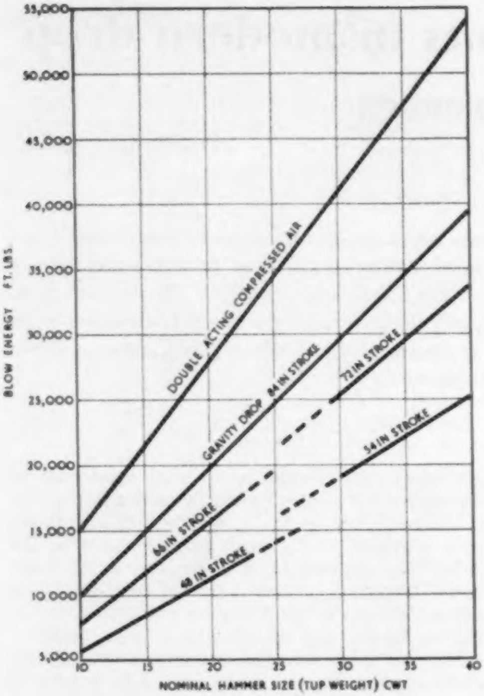
The productive capacity of a drop hammer depends upon four factors: (1) Power, (2) speed, (3) accuracy, and (4) reliability.

Power is represented by blow energy, in a gravity drop hammer the weight of falling parts times the height through which they fall. To a large extent it determines the maximum size of workpiece to be produced. There are other factors whose effect on the hammer's capacity I will detail later, but blow energy is the foremost consideration. Fig. 1 indicates the wide variation in blow energy available from firstly, a double-acting hammer in which gravity is assisted by compressed air and, in the three lower curves, hammers relying purely upon gravity but with varying lengths of stroke. With the different forms of hammers now available for selection, the importance of blow energy in relation to the falling weight is more widely recognized. On the Continent, hammer size is expressed occasionally in kilogrammes of tup weight but more usually in metre-kilogrammes, and this forms the standard basis of comparison. Comparison by weight of tup, usually expressed in hundredweights or pounds, as practised in this country for so many years, may be convenient but is also extremely misleading. This is clearly shown in fig. 1, which is based on the blow energies of standard hammers in wide use today. At the lowest end of the range is the short-stroke Marathon produced by my company. You will see that up to the 20 cwt. it has a 48-in. stroke and the 30-cwt. and 40-cwt. sizes a 54-in. stroke

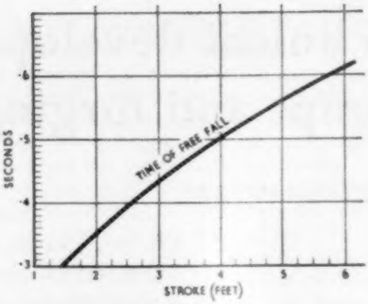
Next we come to what is widely known as the self-contained hammer, with a longer stroke of 66 in. and 72 in. in the larger sizes. The third curve is that of a Bridge-type hammer with an 84-in. stroke up the range. Now, for the same tup weight you will see that the Bridge-type hammer has almost twice the blow energy of the Marathon and the double-acting hammer nearly three times. The difference in blow energy decreases on the larger hammers but is still significant for, in the 40-cwt. size, the double-acting hammer has more than twice the blow energy available than the Marathon and the long-stroke Bridge-type hammer a 75% increase in blow energy. I should point out that these figures have been arrived at after taking into account 10% friction loss in gravity-fall hammers.

In calculating blow energy the maximum weight of die may be added to the tup weight multiplied by the maximum available stroke of tup including maximum die. Resistance to free drop should be deducted to obtain nett effective figure.

I want now to discuss the effect of time and velocity on potential output. Fig. 2 very simply indicates the time of free fall under gravity in relation to the stroke based on the $v^2 = 2$ gs. formula. This is the one inescapable time factor of the gravity-fall hammer. The time taken in falling is proportional to the square root of the height through which the tup falls. While, therefore, it may take half a second to fall through 4 ft. it will



1 *Comparison of blow energies of different types of hammer of similar tup weight*



Time of fling = 0·25 *sec.*

Stroke (ft.)	Time of fall	Time of fall and fling	Blows/min. for zero lifting time
2	0·35	0·6	100
2¼	0·375	0·625	96
2½	0·395	0·65	92
2¾	0·415	0·665	90
3	0·435	0·685	88
3¼	0·45	0·7	86
3½	0·467	0·717	84
3¾	0·485	0·735	82
4	0·5	0·75	80
4¼	0·515	0·765	78½
4½	0·53	0·78	77
4¾	0·545	0·795	75½
5	0·56	0·81	74
5½	0·586	0·836	72
6	0·612	0·862	70

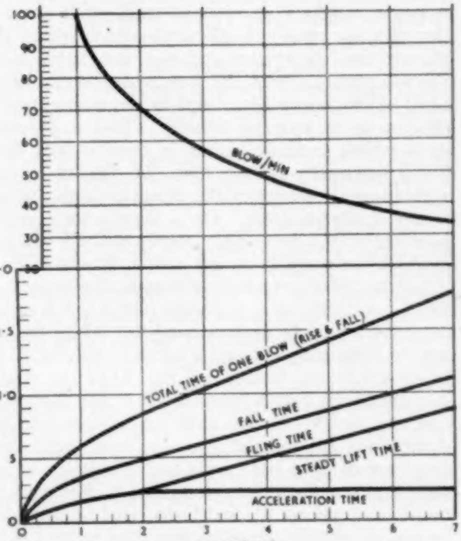
2 *Fall time under gravity related to stroke*

only take 1 sec. to fall through 16 ft. However, loss of heat from the workpiece to the die is of such importance that fractions of a second become a vital consideration. It must, of course, be remembered, too, that the tup must be raised through the equal distance with further loss of time. Furthermore, the velocity at impact can, if high, be in itself a detrimental factor by displacing the metal at too high a rate, particularly in open shallow dies, causing the metal to flow too rapidly past sharp corners and failing to fill the die completely.

Fig. 3 shows a breakdown of the time elements of one stroking cycle of gravity-fall hammers of varying fall heights. The upper curve shows this total time element transmuted into blows per minute. The ' fling ' time is that period which the tup takes to come to rest under gravity at the top of the stroke. This deceleration is quite an appreciable period and various means have been carried out and are at present employed to reduce it, such as hydraulic or pneumatic buffers built into the head gear. The area marked ' fall time ' has already been shown in fig. 1; the total time of one blow is represented by the total distance bounded by the upper curve. I should point out that the lifting speed has been taken between 470 and 500 ft./min. Any further increase in lifting speed has very little effect on the total blow time, so that one tends to arrive at an optimum lifting speed of approximately 480 ft./min.

The effect of increasing lifting speed is shown in fig. 4. Now, what is the effect of time on forgeability? By ' time ' I am not talking about the velocity of impact—I am talking about the actual time between removing a billet with a known calorific content from the furnace or from the moment that it is positioned in the die—from fullering or moulding to the final finishing blow. How much of this heat is lost to the tools, how much to the air, how much to the lubricating medium? What is the rate of loss? What amount of energy from the hammer is converted into heat which will maintain or increase the temperature of the forging? Investigations are being carried out in this field but there is very little exact data available. This is one of the most important factors affecting forgeability to be taken into account by the hammer designer. Excessive time promotes scale and die wear. However, there is the practical consideration

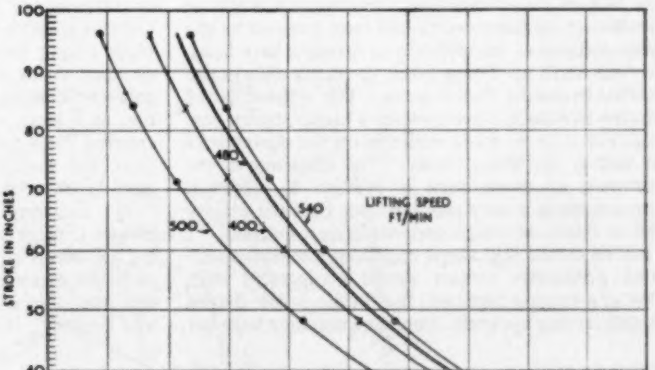
of the rate at which a man can operate a hammer most efficiently. A pneumatic hammer may draw down at up to 250/300 strokes/min., but in impression dies and particularly in team work, where you have two or three men following each other through the hammer, the optimum speed would appear to be of the order of 70/80 *continuously working* strokes/min. Short-stroking double-acting drop hammers (steam or compressed air) are capable of speeds up to 200 strokes/min. but experience shows that the maximum manageable speed is about 120 strokes/min. If an operator misses every other blow, output is seriously reduced and all advantage of high speed lost.



3 ABOVE *Breakdown of the time cycle for single stroke, gravity fall stamps up to 20 cwt. Lifting speed 470 – 500 ft./min.*

I have dealt rather briefly with effect of speed and blow energy. We now turn to their combination: the energy output in a given time. Speed and energy as separate considerations are important. It is the sum of these expressed in ft./lb./min. or mkg./min. for which the hammer maker is endeavouring to design. Here again, this unfortunate method of describing a hammer by its tup weight, however convenient, is not suitable for comparing modern hammers. To give a quick and simple example, an extreme case, take two gravity hammers, each with a falling weight of 1 ton. On the first hammer 'A,' a stroke of 2 ft., on the second 'B,' a stroke of 6 ft. Hammer 'A' would have a possible working speed of 70 strokes/min., hammer 'B' a possible rating of 37 strokes/min., that is 0·56 times the working speed of 'A.' Each of these hammers has a 1-ton tup, one falls 2 ft., the other 6 ft. Comparison as 1-ton hammers is meaningless. Blow energy of 'A' is 2 ft. tons, of 'B' 6 ft. tons. 'B' has three times as much blow energy as 'A.' This comparison now has some meaning determining the ability of the hammer to deform a particular workpiece. Owing to forgeability losses referred to previously, the longer drop hammer 'B' cannot be taken as being exactly three times as effective as the short stroke, but the comparison is not unreasonable.

Hammer 'A' will deliver 313,600 ft./lb./min.



4 RIGHT *Optimum lifting speed for gravity drop stamps*

Hammer 'B' 497,280 ft./lb./min. The 6-ft. drop hammer will give 1·59 times as much energy in a minute. If we replace the tup of hammer 'A' by one of 32 cwt. we shall be getting two hammers which become much more closely related. The comparison is then between a 32-cwt. hammer and a 20-cwt. hammer.

Now why go to a hammer with a larger tup and consequently with the heavier drive? In a high production shop a margin of 10% output either way is the difference between profit and loss. It pays, therefore, to have an overweighted hammer running with a shorter stroke at the maximum speed that an operator can work. On complex stampings which require a degree of fullering or moulding before finishing, the speed at which this can be done is of vital importance. Where, on the other hand, relatively simple, chunky work is required, with vertical rather than lateral displacement and in which the conversion cost is low, hammer 'B,' with its lower capital cost and hence depreciation rate, may be adequate. One further point—hammer 'A' will have a lower striking velocity and wear and maintenance will be appreciably less.

Double-acting hammers

My remarks have been primarily concerned with the gravity-fall-type hammer. I would briefly like to touch, however, on the steam, air or hydraulic driven double-acting hammer, which, in my opinion, has been too long overlooked (Table 1). Steam, unless you have spare capacity for the purpose, is expensive and uneconomic. Compressed air, and in particular the application of heated air, has, in my view, been neglected by the industry. Due to the lack of this stimulation, development work on double-acting hammers has not been pursued by the manufacturer as energetically as it might have been. Serious steps are being taken to rectify this in the electro-hydraulic double-acter. The self-contained electro-hydraulic drive involves a higher capital cost if power is to be made available on the downstroke as well as the lifting stroke. The efficiency of the hammer, *i.e.* work done in relation to electrical consumption, is very much greater than the gravity fall or steam or compressed-air driven machine. I have no doubt that shops requiring a versatile unit with productive output almost comparable with that of a forging press will find in the power-driven double-acting hydraulic hammer a machine superior to anything employed today. But it must be remembered that the tup weight as an indicator of capacity is quite meaningless.

Important design features of the drop stamp

I should like now to deal with several other aspects of the drop stamp which contribute to the accuracy and output of the finished product. Anvil block weight: this, I think, must be regarded as a compromise between what a customer is prepared to pay in weight of cast iron or steel, while ensuring that the tup energy is efficiently employed in displacing the workpiece and not the anvil block. From a purely theoretical aspect, the weight of the anvil block should be related to the momentum of the tup or its striking velocity. This is a subject upon which some difference of opinion may exist, but I personally believe that, for forging in dies, approximately 20 times the nominal falling weight is the optimum ratio. On a short-stroke gravity hammer with a very much slower striking velocity, it *should* be possible to use only a 10 times block. There are, however, other important considerations. Firstly, as I have said, to ensure that as much energy as possible can be absorbed by the workpiece and not in deflecting the anvil block. Secondly, the shock-absorbent feature of the block is related directly to the depth of the block rather than to its intrinsic weight, so that a 20-times block becomes determined by the design. An anvil block with large standard to base areas and a low tup weight ratio is of insufficient depth to absorb effectively the oscillations set up by the blows, and timbers, mat or ground are all subjected to a very much heavier stress. Certainly excessive deflection can, of course, be compensated for by specially sprung foundations, but this all adds to the expense of the installation. With a light block the more importance must be attached to the timbers, mats and general depth of concrete beneath the block. Lightness of block can, to a large extent, be compensated for by increasing the weight of the concrete inertia block but there will always be the greater tendency for the anvil block to bounce.

My company, with the assistance of the Manchester College of Technology, is continually studying the effects of stress on the main frame members of drop hammers and it was largely as the result of this work that a box-form construction of standard was adopted. Cast iron absorbs vibrations better

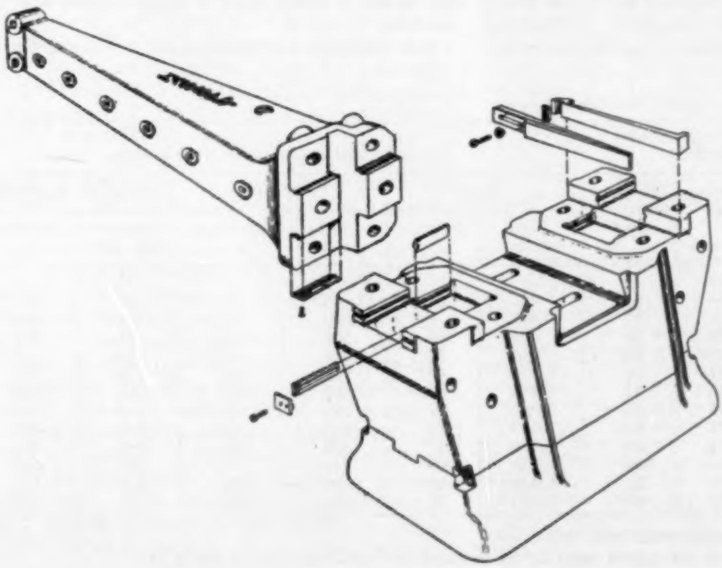
TABLE 1 *Maximum blow energy available per minute (ft. lb./min.)*

Nominal tup weight (cwt.)	Self contained		Marathon		Double acting (comp. air)	
10	(5 ft. 6 in.)	290,000	(4 ft. 0 in.)	282,500	(2 ft. 9 in.)	1,800,000
15	(5 ft. 6 in.)	445,000	(4 ft. 0 in.)	426,000	(3 ft. 0 in.)	2,925,000
20	(5 ft. 6 in.)	590,000	(4 ft. 0 in.)	565,000	(3 ft. 0 in.)	3,130,000
30	(6 ft. 0 in.)	890,000	(4 ft. 6 in.)	885,000	(3 ft. 2 in.)	4,120,000
40	(6 ft. 0 in.)	1,180,000	(4 ft. 6 in.)	1,180,000	(3 ft. 2 in.)	5,100,000

than steel due to its lower elasticity; it is not so resistant to sudden shock, and a size of hammer and anvil block is soon reached where steel is preferable. The designer must aim for maximum rigidity and shock absorption in his design of standard commensurate with an economical use of metal. Whichever line of approach is taken, it is accepted that the standards must not deflect under the enormous side thrusts from the tup at time of impact and the short-stroke hammer does permit the same mass of metal to be disposed with a lower centre of gravity and spread over a wider base to block area than in the standards of the long-drop hammer. This low centre of gravity seems to me to be of great importance. Unbalanced concentrations of metal, irregularly distributed would appear to develop oscillations of varying frequency resulting in excessive stresses in the standard, accentuated in stamps of longer stroke. Within the limits of practical design, the trend is to achieve a low centre of gravity. However, it seems to me preferable that the hammer itself should be built up of separate components and that a combined block and standard design is to be avoided. Failure of any one component part, involves replacement of the whole hammer. Stresses are unpredictable and no overload protection can be incorporated as a safety measure. Independent units of balanced design insulated from each other by rubber-impregnated fabric pads or shock-absorbent jointing material are more resistant to shock, and in the event of failure any one component can be replaced without almost total loss.

There is, furthermore, one peculiar characteristic of your side frames, particularly if they are heavy. When the blow is struck, the inertia of the side frames prevents them immediately following the downward displacement of the block and very heavy tension stresses can arise at the feet of the columns where they adjoin the main block. Momentarily, as the block goes down, the columns tend to stay behind. Elasticity of jointed construction absorbs some of this stress. In the past the block to standard joint has suffered from severe fretting and abrasion on mating surfaces. However, the adoption of shock-absorbent materials between standard foot and block and on spigot facings has, as we have found from trials carried out in our shops, provided pronounced resistance to wear between these surfaces, so that after 12 months' work we were still able to identify the original machining marks on the surfaces of the block and the anvil feet. Holding-down bolts, slide bolts and fixing bolts generally, should be of ample length, so that full advantage of their elasticity can be obtained. Hard-rubber bushes and washers suitably disposed help to absorb shock. There is a momentary elongation of the bolts at the time of stress, and nuts must be secured by locking devices to prevent them working loose.

I have mentioned the importance of large base area to reduce the loading per square inch on the feet of the standards. Fig. 5 shows the locating faces of modern hammer standards, *e.g.* spigots—abutment—surface area. Table 2 shows very clearly why this has been increased on the new



5 *Exploded diagram of standard to block joint*

designs of hammer. The large horizontal surface area is very valuable, reducing wear and increasing stability. In addition, the area of vertical abutment which takes the main thrust at time of impact has, as you will see, in the case of new hammers, been increased by as much as 400% and in some cases more. Spigot areas, which take the side kick, have been increased from about 115–120% on the smaller sizes; up to as much as 219% on the heavy drop stamps. We have now developed non-metallic, replaceable wearing strips fitted to the spigot faces, obtaining thereby exclusion of scale and greatly increased resistance to wear.

In some designs the exclusion of scale from the standard to block joint has been improved by raising the joint line to a position level with or above the die line. There are two design difficulties which arise here: (1) the weakness of section which arises at the juncture of the projecting horns with the block—there is a very nasty moment applied here; (2) with replaceable slides, that is loose slides in the standards, they cannot be extended far enough down to give adequate guiding to the tup.

I turn briefly to the design of slides and the vee guides. Where the vees are solid with the standards, maximum stability of tup is achieved by arranging them as far apart as possible. However, the loose slides which can be reversed or easily removed for repair are preferred. Separate loose slides have an inertia of their own, they must, therefore, be as light as possible. They must be held securely and rigidly. They must be readily removable. They must be hard enough to resist wear but tough enough to resist shock, or cracking and fracture will occur. This is one of the difficulties of designing loose slides for the larger sizes of long-fall hammers. The weight and inertia of these slides makes them extremely difficult to secure solidly and firmly to the hammer standards. To counteract wear, chromium plating of the slides has been satisfactorily employed. The practice of applying a Sulfinuz treatment to the surface of the vees which we developed with I.C.I. is already being more widely adopted and is increasing the life of slides between re-machining by as much as four and five times. We have done much work on the automatic application of lubricant to slides. With intermittent operation, it is difficult to ensure the correct amount of lubricant being applied at the right time. Gadgets tend to fall off hammers. Excessive oil dripping on to the die area is a nuisance. If trouble is taken to meter the flow of oil correctly, automatic lubrication can make a valuable contribution to slide life.

Slides may be fixed or adjustable. In some companies it is the practice to take all adjustment on the hammer entirely out of the hands of the operator. In others, the operator must make his own. There is much to be said for securing the standards solidly on the block and taking up tup and slide clearance by adjusting the slides. I personally feel that cross adjustment of the standards, provided that it is quick, simple and positive, is preferable to adjusting slides by means of the wedges or tapered bolts. Compensation for temperature variation or offset is unavoidable and I see no reason why minor cross adjustments during working should not be carried out by the operator. We ourselves are reverting to this course on our short-stroke hammers, though where a stipulated preference for an adjustment of the slides is made such a design would still be available.

I do not intend to develop the arguments for or

TABLE 2 *Comparative areas of feet of hammer standards*

Size of hammer	Self-contained and old-style rigid guides			Marathon and super design rigid guides					
	Base area (sq. in.)	Spigot area (sq. in.)	Wedge or abutment area (sq. in.)	Base		Spigot		Wedge or abutment	
				Area (sq. in.)	Increase (%)	Area (sq. in.)	Increase (%)	Area (sq. in.)	Increase (%)
5φ/7φ	232	24	9	—	—	—	—	—	—
10φ	324	34	11	441	36	69	103	60	445
15φ	440	38	12	441	0	69	82	60	400
20φ/25φ	465	46	21	676	46	102	122	83	295
30φ	685	63	23	910	33	136	116	108	370
40φ	726	74	34	1,074	48	162	119	139	309
50φ	848	85	35	1,216	43	180	112	160	356
3T	923	85	38	1,301	41	190	123	178	369
4T	1,034	92	42	1,433	38	236	157	211	400
5T	1,102	92	42	1,624	47	260	183	236	462
6T	1,049	100	46	1,768	69	277	177	252	448
8T	1,349	100	68	1,948	45	319	219	293	330
10T	1,513	132	90	1,989	31	356	170	332	269

The base areas quoted are for one guide only.

Spigot areas are for one side of the spigots only, *i.e.* for thrust in one direction, and for one guide

against poppetts and dovetails for securing the dies in the block, but would make this comment. After the Productivity Team visited United States forges in 1949, my company changed its policy from recommending poppetts, and recommended the dovetailed dieholder. This policy was pursued for a number of years, but resistance was such that we have, on our gravity-drop hammers, reverted in general to the poppett design, though dovetailed blocks can readily be supplied as an equal alternative if preferred. I can readily see the advantages of the poppett design in setting and adjusting the dies, but I believe that if drop forgers are prepared to employ high-energy hammers, particularly of high impact velocity, then they must accept the dovetailed dieholder. We would not, for example, consider employing poppetts on compressed-air double-acting hammers.

Trends in hammer design

The trend of hammer design is towards adjustable stroke, varied to suit the job, controlled by a foot switch giving long or short blows at will. On the other hand, little work in this direction has been done on the board hammer and its efficiency depends upon its effective blow rate. Where, therefore, a job combines drawing down requiring light blows with heavy blows to finish, the board hammer is at a disadvantage. If, however, the human element is accustomed to working at a high continuous rate on a constant stroke hammer equally good production can be obtained off the board hammer.

An operator trained to select the blow according to the job will reduce wear and tear on the hammer and operate it at a higher efficiency. However, with the adjustable-stroke machine, a further possibility arises of introducing a programmed stroke control. The number and length of blows are pre-planned and the sequence set on an indexing gear which then controls automatically the number and energy content of blows delivered by the hammer. From the point of view of production planning, sequence control presents considerable possibilities. Its design can take into account stopping or starting part way through a sequence and re-setting to recommence the sequence at any point by simple pressure of the foot pedal or a separate switch. Experience has shown, however, serious operator resistance to this type of control which, in the particular case I have in mind, has largely invalidated it. Like all semi-automatic or automatic processes, its successful operation depends on close control of material quality, size and temperature; but so, for that matter, does production under a forging press. The chief difference, however, is that a forging press does not require a skilled operator, whereas forging under a drop hammer develops a degree of skill which the operator would be loath to lose. If you could remove all the elements of skill from the job, sequence control would automatically come into its own.

The advantages and limitations of counterblow hammers—horizontal and vertical—together with forging rolls, upsetting machines and preparing hammers are outside my terms of reference. I should, however, like to make reference to the trimming press, which particularly in this country runs parallel with the hammer. The wide-frame type of press which was introduced by one of our worthy competitors some years ago, and I may say most successfully, does appear to be having, with the advent of improved sizing or calibrating requirements from the automotive industry, a much broader demand. It is, of course, especially suited for use with forging presses, whose very employment indicates a desire for more closely finished components, and this type of press is steadily encroaching upon the well-tried and still extremely useful narrow table press with its outside clipping tool. I believe that this trend will continue.

to be continued

Cobalt-modified high-strength steel

A MAJOR development for the missile industry came with the Mellon Institute's announcement of a new high-strength steel. A cobalt-modified SAE 4137 grade, it possesses ultra-high strength, good ductility, low notch sensitivity, easy formability, and good welding characteristics.

Tests on full-scale rocket engine cases show that this new material, designated MX-2, can be used in parts requiring yield strengths of 225,000 to 235,000 lb./sq. in. Mellon is continuing tests on deep-drawn rocket cases with a wall thickness of 0·035 in. It is believed that these will replace others having a 0·050-in. wall thickness, with a resultant saving in weight of 20%.

The % composition of the new steel is:

Carbon ..	.. 0·39	Sulphur ..	.. 0·01
Manganese	.. 0·70	Chromium	.. 1·10
Silicon ..	.. 1·00	Molybdenum	.. 0·25
Cobalt ..	.. 1·00	Vanadium	.. 0·15
Phosphorus	.. 0·01		

It is being produced commercially by Universal-Cyclops Steel Corporation under the trade name of Unimach UCX2.

Conference on cold extrusion

A special conference on the cold extrusion of steel is being held by the Institute of Sheet Metal Engineering, at the City Hall, Sheffield, November 21-23.

Admission to all technical sessions is by ticket only which are available without charge to members of the Institute of Sheet Metal Engineering and of the National Association of Drop Forgers and Stampers. Non-members of these bodies are welcome to attend on payment of a registration fee of 3 guineas. Buffet luncheon will be available on each of the two full meeting days and preprints of the papers will be circulated prior to the conference to those who apply for them.

Application forms may be obtained from the Hon. Secretary, Institute of Sheet Metal Engineering, John Adam House, 17-19 John Adam Street, Adelphi, London, W.C.2.

Russian forging journal

Abstracts from the Russian forging journal—Kuznechno-Shtampovochnoe Proizvodstvo, March, 1960, **3.** *This is the second year of this journal devoted specifically to forging. We shall try to give indications of the contents of future numbers in* METAL TREATMENT *each month.*

The geometric similarity of hot-working processes (an assessment). N. M. ZOLOTUKHIN. Pp. 1–3.
A review is given of previous literature on the law of similarity of the elastic deformation of metals first outlined by V. L. Kirpichev in 1874. The development of this theory is discussed in relation to the modelling of hot plastic deformation processes. The size factor is considered to be most important for the behaviour of metals during these processes since the heat-transfer conditions in thick bodies are radically different.

Mechanical working by the vibration method. M. YA. KARNOV and A. A. VORONIN. Pp. 3–8.
A report is given on the results of an investigation of the process of vibration forging on the 350 metric ton hydraulic vibration forging press described in detail. Comparisons were made between forging on this press and on a conventional press with preparation of deformation-load, plasticity-temperature and other diagrams, and an examination of microstructures of forgings. Deformation was shown to be more even throughout the volume of the forging, friction on the contact surfaces was reduced by up to 60%, plasticity was increased by up to 40%, the load was reduced by 30/50%, and dimensional accuracy of the forgings was considerably improved.

Problems of the improvement of the stamping of automobile components and the stampability of sheet steel. V. M. CHIRKIN. Pp. 8–10.
As criteria of the stampability of steel, in Russia, use is made not only of the hardness and yield point and the results of Erichsen tests, but also assessment based on the limiting diameter of a billet which can be drawn without rupture on either a mechanical or hydraulic device. In the absence of a completely satisfactory tests of stampability, the author suggests that this should be assessed on the basis of hardness, Erichsen tests and the results of tensile tests (relative elongation, yield point and tensile strength). In addition an analysis of the microstructure should be used to control the upper limit of grain size, while a lower limit is not considered necessary. It is suggested that steels should be chosen strictly in accordance with the difficulty of stamping a given component. The standard of difficulty might be assessed on the basis of the value of the bending angle, that of the radius of bending, and that of drawing. On this basis suitable standards for the mechanical properties of sheet metal could be compiled. By this means, higher production costs for steels with higher mechanical properties would not be unnecessarily wasted; likewise non-age-hardening steels should only be used where this is essential.

The effect of the degree of forging on the degree of penetration during ultrasonic testing for forgings in high-alloy heat-resisting steels and alloys. M. YA DZUGUTOV, YU V. VINOGRADOV and V. P. STEPANOV. Pp. 10–13.
The method of calculation of the forging coefficient, or degree of deformation, is outlined, and typical examples are given for forging processes, *e.g.* cogging of an ingot, upsetting, etc., and these coefficients were related to the results of ultrasonic testing. Consideration is also given to the influence of heat treatment on the degree of penetration by ultrasonic waves. In the light of the experiments it is found that: (1) the value of the total deformation under otherwise equal circumstances exerts a decisive influence on the penetration of ultrasonic waves up to a definite limit, and with the increase in the forging coefficient the degree of penetration of forgings by ultrasonic waves is improved; (2) at one and the same forging coefficient the degree of penetration of forgings is worsened, as the dimension of forgings in the direction of testing is increased; (3) the degree of penetration is also influenced by the nature of the alloy or steel under test; (4) the use of special heat treatment of forgings which cannot be completely penetrated, or only partially so, by ultrasonie waves in the state after forging normally leads to an improvement in the degree of penetration thanks to the more complete fulfilment of the process of recrystallization of the cast structure.

Designing dies for upsetting and piercing wheel billets. M. YU. SHIFRIN. Pp. 13–16.
A method of calculating the forging dies in a wheel plant before rolling of the wheels is set out.

A method of calculating the layout of rolled material of moderate length and the waste cuts. V. L. RASKIND. Pp. 16–18.

Automation of the control of profiling and tube profiling press mechanisms. L. V. BARANOV. Pp. 19–24.

*A mechanized stamping line for external door panels of the GAZ-*51 *automobile.* N. P. YASHNOV, V. V. KOLOBOV and G. B. GREKOV. Pp. 24–27.

Non-oxidizing heating of steel in continuous, three-zone furnaces with the use of oxygen. S. E. BARK, A. V. KOZLOVA, V. M. KUVSHINNIKOV, M. I. SKVORTSOVA and V. A. USTINOV. Pp. 28–33.

A full description is given of the design and trial operation of the furnace which is fired with natural gas (methane), with up to 40% oxygen enrichment of the air for combustion (excess air coefficient 0·507). The burner design and charging mechanism are also described.

The efficiency of forge shops. V. I. GANSHTAK and B. I. MAIDANCHIK. Pp. 34–36.

A report is given of data obtained during investigations of forging shops carried out by scientific research institutes and design organizations of the Sverdlovsk Economic Region during the years 1958–59.

A counter of the working strokes of crank-drive presses. A. D. KIRITSEV. Pp. 37–38.

The counter designed by the author is described in detail.

An automatic press for manufacturing spring washers 5·5 mm. in diameter. SH. N. BEKKERMAN. Pp. 38–39.

Experience in the adoption of dies with changeable inserts for hot forging. N. V. VOLCHKOV and I. B. FUTERMAN. Pp. 39–41.

Hammer forging of small runs is uneconomic due to the high cost of making special dies and the extension of the forging production cycle. The aim of this article is to indicate how these disadvantages may be overcome.

A combined-action press for drawing box components. A. G. OVCHINNIKOV. Pp. 41–42.

Design and fabrication technique for hard alloy dies. B. S. SEKUN. Pp. 42–43.

The article outlines the production of fine-grain tungsten-cobalt alloy dies. Operational experience of their use showed that the life of the dies was increased by 50 times or more by comparison with that of steel dies, and corresponding increases in the life of other mechanical working tools. There is a considerable improvement in the quality of components produced with these tools, consistency in their dimensions is maintained over a long period of operation, and there is a considerable saving in down-times for changing tools.

Experience in the use of articulated-bending presses. V. A. LOSKUTOV. Pp. 44–45.

Review of a book 'Bending of Tubes.' A. I. GAL'PERIN. Published by Stroiizdat, Moscow, 1958. Pp. 130.

Forging trainees

SO SUCCESSFUL has been a co-operative training scheme introduced three years ago by 12 Sheffield steel-forging firms that a pilot scheme for rolling mills has been started with three firms participating. Results must be studied before any further scheme is put into operation, but the need for one for melting shops is being considered and reports and proposals have been made for wire-drawing departments, according to the Bulletin of the British Productivity Council.

The training course, introduced in 1957 by the forging firms' co-operative, has a syllabus covering two years.

Of the firms concerned, five employ more than 1,000 and seven fewer than 600—with the smallest employing 50.

Most large companies do much to train their own recruits and, generally, can provide better opportunities than smaller concerns. Even so, individual training is often impossible, in large *and* smaller firms, because of the relatively high costs and the time involved.

The aim of the Sheffield scheme is to provide equal facilities for all trainees. As a preliminary to the course, recruits attend induction sessions at which they acquire a background knowledge of the industry. Then, in easy stages, they are introduced to trade practices.

Three days each week are spent by trainees at their own works where they are given instruction in forging and gain knowledge of the work in related departments.

One day a week is devoted to training elsewhere under an instructor and the fifth day is used in study for the iron and steel operatives' certificate of the City and Guilds of London Institute.

Originally, three firms provided forging hammers at a nominal rent. But the scheme has proved so successful —24 are on the current course—that the sponsoring firms agreed, last year, to buy an electrically-operated hammer for use by the trainees; this was installed at the works of a member firm.

The scheme is financed by a £75 fee for each trainee, which permits the employment of a full-time forge instructor who works in close co-operation with his opposite numbers in member firms.

Trainee on the 2-cwt. electric hammer at Hall and Pickles, Sheffield. The hammer is used by the company blacksmith but on two days a week it is devoted to training

Boron and silicon

A striking feature of the metallurgical scene during recent years has been the gradual emergence into importance of the rarer metals and other elements. This has largely resulted from the demands made by newer industries for materials with special properties and this has in turn resulted in improved methods of production, making supplies of hitherto scarce elements available commercially. Boron and silicon are two such elements and the present article describes developments in their use as pure crystalline metalloids

DURING the last quarter of a century or so the two elements boron and silicon have undergone a complete transformation as regards their role in metallurgy and in applications as pure crystalline metalloids. As borax and other borates and as silica and silicates, the two elements have been regarded as of use to industry only as these oxy-compounds, apart from silicon steels and boron steels of older types. Now that crystalline boron and silicon have become commercially available as pure forms rather than types contaminated with aluminium, magnesium and carbon as with early production processes, a review of modern production and applications will illustrate the changes which have taken place.

Boron—early reduction methods of

First attempts to produce boron from boron oxide or boric acid were made long ago by Humphry Davy, who tried the electrolytic decomposition of boric acid, and by Gay-Lussac and Thenard. These all carried out the reduction of boric oxide with potassium, a method giving an impure product and with no promise even when more recent workers improved technique. Boron is described in textbooks even today as existing in two forms—a crystalline form or 'adamantine' boron now known to be an aluminium boride AlB_{12}, and a chestnut brown powder shown to be a sub-oxide.

It was in 1909 that Dr. E. Weintraub of the General Electric Company described in the Transactions of the American Electrochemical Society the preparation and properties of pure boron. He passed a high alternating current between cooled copper electrodes in an atmosphere of pure boron chloride and hydrogen in large excess, this winning pure fused boron so different in properties from the impure amorphous boron always obtained by the textbook reduction of the oxide with magnesium. The amorphous boron made by Moissan and others is, however, an industrial product marketed for use where pure boron is not essential. Weintraub's boron prepared either as fused pellets or powder is at least 99·8% pure and is expensive for large-scale use; yet it is of value not only where the highest purity is needed regardless of cost, but as a standard by which to assess other productions.

Van Arkel, noted for the thermal iodide process for preparing highly pure metals, also took interest in boron, this being evident in his 1930 U.S. patent, in which boron is produced by dissociation of a halide such as the bromide on a heated tungsten filament. Then to illustrate the interest in pure boron and the close comparison with the new industrial silicons of high purity, came reduction processes for boron hydrides or boranes in which the Atomic Energy Commissions of Canada and of the United States have been associated.

Modern production of boron

Since all such processes from boron halides or hydrides are uneconomic for large-scale use, yet further improvements were introduced after much research. Thus in 1951 Fetterly of the Norton Company used boron chloride and hydrogen as raw materials, but deposited the pure boron on carbon resistors at 1,400°C., the upper layer of boron being formed on a boron carbide layer.

Still more promising are electrolytic techniques, modern processes reminding us of Davy's hint at electrolysis when he passed a current through boric acid and noticed a combustible product at the negative pole. In 1927 L. Andrieux described a new process for boron in which a fused bath of boron oxide, magnesium fluoride, with some magnesium oxide, was electrolysed at 1,100°C., using a carbon anode and an iron cathode. Then in October, 1951, H. S. Cooper of Cleveland, Ohio, patented two electrolytic methods for industrial boron yielding the element of from 99·4 to 99·7% purity. In the first of these a mixture of potassium fluoborate with potassium chloride is electrolysed in a graphite-lined pot or cell, the cathode being an iron plate bolted to a water-cooled copper terminal; in the second some boron oxide is included in the fused bath contents. The resulting boron can be shaped by hot-pressing or cold-pressing with sintering to follow, hot-pressing needing a temperature of 2,000°C.

Uses of boron

Turning now to industrial applications and to the role of boron as distinct from the many older uses of boric acid and borates, developments during the last two or three decades have included the introduction of the element as well as of new alloys

and boron steels, with borides of rarer metals potential rivals to carbides. Boron resists boiling hydrochloric and hydrofluoric acids and is almost unaffected by hot sulphuric and chromic acids; yet up to the present there have not appeared applications of boron protection of metal surfaces on the lines of 'siliconizing.'

The element is in demand in the atomic field since when incorporated in plastic aluminium it forms lightweight neutron shields with its neutron absorbing powers. It has been adopted in electrical resistors, in gramophone needles, in thermal cut-outs for transformers and in pivot-bearings. With its high affinity for oxygen, boron is highly efficient in treating copper, brasses and bronzes for removing gas, this in the case of copper yielding a metal of high conductivity. Copper-boron alloys are used in this field with a rival in calcium boride produced by electrolysis of a molten bath of boric oxide and lime. The higher cost of boron has held back the proposal to use it in place of silicon or aluminium as a reducing agent in metallurgy.

Borides of a number of metals have been produced by direct combination at a high temperature within a vacuum or by heating in an inert gas. Electrical contacts of boron with silver are covered in a 1939 American patent, while the borides of niobium melting at 2,900°C., of tantalum (3,100°C.), of tungsten (2,860°C.) and titanium (2,900°C.) are now under close study since they may usually be sintered and hot-pressed and will withstand high temperatures and resist scaling. Boron nitride, a white powder of m.p. 3,000°C., resists oxidation up to 650°C., has a high electrical resistance, and may prove a special pigment of high resistance to attack. The carbide exceeding diamond in hardness is an abrasive.

As ferroboron and manganese-boron added to a steel bath, boron increases hardenability and serves to replace more costly molybdenum and chromium. Boron or its alloys are naturally only added to a completely deoxidized steel bath to avoid wastage of relatively expensive boron. In steel, boron up to 0·003% is commonly specified, yet apart from such very small inclusions the metallurgist today is using increased proportions of boron for special steels of medium and high carbon types. Thus in control rods for atomic reactors 2% boron began to be incorporated in steels, while up to 5% boron appears in cast tubes or 3·8% in extruded tubes for the Calder Hall units.

Although boron steels were studied by Guillet in 1907, it was only in 1921 that the very small additions of boron for the desired effect were appreciated for grain refinement. The Second World War brought much impetus to boron steel production in order to conserve other alloying elements. In 1949 a high-strength low-carbon molybdenum steel with the boron doubling the yield-stress value was described before the Iron and Steel Institute by Bardgett and Reeve, while a review of American practice in 1952 told of a widespread use in the automobile and allied industries.

Production of silicon

With crystalline silicon of high purity outbidding germanium in the transistor field and now produced in such new factories as that of I.C.I. on Merseyside, this element has been developed far more than boron though in similar directions. As with boron the metalloid silicon was produced long ago by Gay-Lussac and Thenard by reduction of silicon compounds with potassium, the fluoride being used. Berzelius heated at a high temperature silica, iron and carbon to form iron silicide, and then went further by preparing amorphous silicon by reduction. Deville prepared shining plates of crystalline silicon by electrolysis, and in his acid extraction method for ridding silicon of metals and silicides as impurities, he anticipated the way in which one type of 'hyper-pure' silicon is now produced.

Moissan, in his famous electric furnace, produced a silicon of 97% purity, one which by acid extraction could be converted to 99% purity, and thus opened the second procedure for manufacturing silicon of less purity than that required for transistors yet of far less cost. Silicon carbide was the normal product from sand and coke in the electric furnace; yet on varying the proportions and conditions it was found that large ingots of up to 800 lb. commercial silicon could be made from this reaction. H. N. Potter and Acheson were prominent in developing such production methods for commercial silicon of low cost, yet sufficiently pure for normal metallurgical uses. All references to industrial silicon are, of course, to the crystalline metalloid since amorphous silicon, a brown powder, has remained a laboratory curiosity.

Corrosion-resistant properties of silicon

With silicon so resistant towards corrosive agents, it was to be expected that industrial applications would be sought for this crystalline product despite its intractable nature. The carbide or carborundum had become established as refractory; hence when it was discovered that inclusion of higher proportions of free silicon element increased the refractory or resistant properties, the use of free silicon became studied.

In 1933, in the United States, came the 'siliconizing' process in which ceramic articles were fired with silicon, while iron and steel castings were also siliconized or 'Ihrigized' as it became known after its inventor. The treating of metal

surfaces is thus carried out by first cleaning them, then embedding the articles in silicon carbide or ferrosilicon in a furnace at 1,000°C., and using chlorine to form silicon tetrachloride vapour within the furnace, this being dissociated to form silicon layers of up to 0·1 in. in depth on the metals. The steel so treated is completely resistant to acids. Silicon has also been tried out cast into chemical plant, while bright layers of the metalloid have been applied in special mirrors.

Silicon for transistors

An entirely new industry using silicon came when 'hyper-pure' silicon was adopted in transistors in place of germanium. Ten years ago the reduction of silicon tetrachloride vapour by use of zinc became appreciated as the only way to produce highly pure silicon for the electrical industry, the cheaper production from silica being suitable only for large-scale production of commercial grades. The Dupont research demonstrated how pure silica ware was the only material possible for the process, this because of the exceptional affinity of silicon for most elements. Hydrogen reduction was tried yet proved less practical than zinc, while Van Arkell's 'iodide' process in which a hot filament decomposes silicon iodide was too costly.

Zinc reduction, using zinc vapour at 950°C., yielded silicon of 99·7% purity, cancelled the need for protracted acid leachings, and formed a silicon ready for zone refining. This method used for preparing transistor silicon depends on the segregation of impurities at one end of a silicon ingot when silicon in long quartz tubes is melted, the electrical heating being withdrawn slowly so that solidification brings about concentration of impurities at one end of the resulting silicon rod, these ends being cut off. Such new techniques have improved greatly the melting techniques within vacuum furnaces and the preparation of single crystal silicon by the drawing method.

Silicon as an alloying element

The applications of silicon in silicon brasses with up to 3·5% silicon improving mechanical properties, and in aluminium alloys with up to 13% silicon, represent outlets in the non-ferrous field as do copper-silicon alloys as substitutes for tin bronzes.

Silicon added as ferrosilicon to the steel bath lowers the temperature at which gases are evolved from the molten metal and hence is an essential for ensuring 'killed steel.' Ferrosilicon thus became the chief de-oxidizer in open-hearth steel production, this bringing the replacement of blast furnace-produced ferrosilicon of only 15% silicon by the 50% product prepared in the electric furnace. Two wars have widened the role of silicon in the ferrous industries considerably. Higher proportions of silicon than the original 0·3% brought high-permeability steels for transformer cores after Hadfield had demonstrated in Sheffield the superior value of high silicon steels or silicon irons in transformers.

Apart from high-permeability steels, heat-resisting steels and other high silicon steels which have appeared within the last 25 years, mention must be made of developments in high silicon irons for the chemical industry. In 1903 a patent for silicon iron was granted to Jouve for a product with 17% silicon, this being followed by other silicon irons in Italy, in Germany by Krupp, and in America by the Duriron Company. In Britain the Lennox Foundry Company championed Tantiron, the British standard specification of 1949, giving irons with up to 15·25% silicon.

In World War II high silicon irons became required in vastly increased quantities, since they replaced stainless steels for many purposes. For resisting sulphuric and nitric acids and solutions of their salts, as anode material for cathodic protection, and in the general chemical engineering field for mixing vessels, pumps and pickling vessels, this form of industrial silicon is invaluable. 'Some day the commercial world will decide where ferrosilicon ends and silicon metal begins. I have in mind a product of at least 95% silicon in which iron would be considered an impurity.' That statement of F. M. Becket in a Perkin Medal address is a hint at the possible expansion of industrial silicon in metallurgy.

Metallurgy in nuclear power technology

concluded from page 432

will be used as a fuel, but in an alloyed form it is far more acceptable.

Plutonium-bearing uranium alloys behave very similarly to uranium under irradiation, and exhibit surface roughening and growth with swelling at higher temperatures. Plutonium does not appear to affect the fundamental causes of growth and swelling, but at the same time it does not appear to make these phenomena very much worse than in the unalloyed uranium fuel bar.

A limited amount of work on the irradiation of plutonium in non-fissile matrices has given encouraging results at moderate temperatures. Aluminium containing 1·7 wt.% plutonium irradiated to 60% burn-up of plutonium atoms at 400°C. maximum has been reported as showing a uniform volume increase of 1·4%, no observable change in microstructure, but a considerable increase in hardness.

Metallurgy in nuclear power technology

4. Behaviour of fissile metals under irradiation

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles which are appearing monthly in this journal

URANIUM is exposed to many kinds of radiation in a reactor. Electrons and γ-rays are quite intense but their principal effects are ionization and heating. Alpha rays are present but their effects are not significant. The most important sources of damage are neutrons and fission fragments.

Everything in the core of a nuclear reactor is bombarded by radiation, principally neutrons, which produces damage of two main types. By knocking atoms out of their equilibrium lattice positions direct damage is caused. When irradiation changes the atomic nuclei, in effect producing new elements or allotropes, indirect damage is caused.

Neutrons, being electrically neutral, pass through an atom, unconcerned about the electrical fields of the nucleus or the electron cloud. Consequently, most neutrons pass straight through an atom without disturbance to the path of the neutron or to the position of the atom concerned. Occasionally, a neutron hits the nucleus of an atom, but the proportion to do so is small because of the smallness of the target presented by the nucleus.

The cross section of the nucleus target varies widely from one type of nucleus to another and also with the speed of the neutrons and the type of collision taking place. It is thus a more complex quantity than the fundamental projected area of a nucleus. In general, cross sections may be expected to vary inversely as the neutron velocity, since the shorter the time for which the neutron is in the immediate vicinity of the nucleus, the smaller its chance of interaction. In other words, a slow neutron is more likely to be influenced than is a fast neutron, so a given nucleus spreads its influence over a larger area than its physical projected area to slow neutrons but not to fast ones.

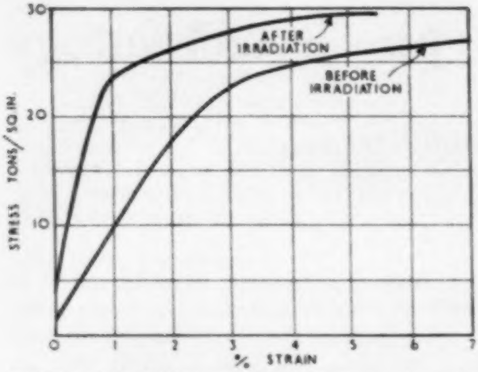
In addition, resonance can occur between the energy of vibration of an atom and a neutron having a certain critical energy level, or velocity. When this occurs, it is tantamount to saying that the system 'atom nucleus plus neutron' is preferred to the energy of the nucleus alone. Since many more neutrons are likely to be affected by such a resonance condition, the effective cross section of the nucleus suddenly rises at these particular energy levels.

To be able to compare one type of nucleus with another, with regard to its effect on neutrons, it is convenient to refer to its effective cross section. It is normal to take the total or maximum possible cross section of a nucleus for interaction of any kind, with fast or slow neutrons and for absorption or scattering, and express it in barns. A barn is a measure of the effective cross section of a nucleus to neutron irradiation and one barn is a unit of 10^{-24} cm^2. Table 10 lists a few typical neutron-capture cross sections, *i.e.* the maximum cross sections of the nuclei concerned, in barns.

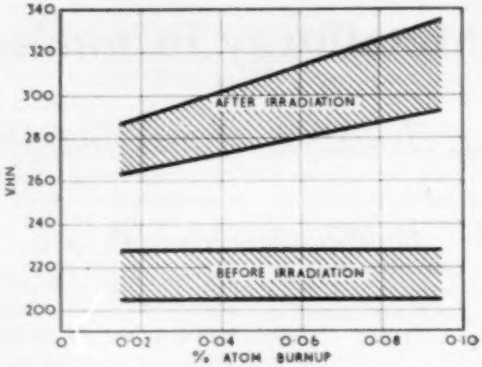
TABLE 10 *Typical neutron-capture cross sections*

Element	C/s (barns)	Element	C/s (barns)
Deuterium	0·0006	Lithium	65
Beryllium	0·0085	Boron	700
Carbon	0·0048	Cadmium	2,500
Magnesium	0·06	—	—
Zirconium	0·18	—	—
Aluminium	0·24	—	—
Iron	2·50	—	—
18/8 Stainless	2·90	—	—

The elements in the left-hand column, particularly the first six, have low effective cross sections and consequently are of great interest in moderating neutrons or in structural units in the reactor to



17 *Effect of irradiation on stress/strain curves of uranium*



18 *Hardening of uranium as a function of burn-up*

conserve neutron economy. On the other hand, elements such as boron and cadmium are capable of 'mopping up' neutrons and consequently would be used in control rods which, by absorbing excess neutrons, hold the chain reaction of a reactor in check.

Two possibilities exist when a neutron does manage to strike a nucleus. The neutron may be deflected from its line of approach to the nucleus or be 'scattered,' or, alternatively, it may be absorbed into the nucleus.

Scattering

Only fast neutrons (speed about 2 MeV. equivalent to 2×10^9 cm./sec.), freshly created from a nuclear fission, produce damage by scattering because only they have sufficient energy to give a large recoil energy to the struck nucleus. A slow, moderated or thermal neutron has an energy of about 0·025 eV. (speed about 2×10^5 cm./sec.) whereas the energy necessary to move the average atom from its equilibrium lattice site to become an interstitial atom and leave behind it a vacant site, is about 25 eV. Thus, a thermal neutron has insufficient energy to eject atoms from their lattice sites. However, a fast neutron has an enormous excess of energy to do this and, of course, the ejected atoms will receive very high energies after the collision. So much so, that they may well collide with another atom and displace it; the process continuing until the energy has been reduced below that necessary to eject an atom from its site.

Absorption

Another source of high-energy particles is the result of an atom absorbing a neutron. The new nucleus formed is usually unstable and, in an attempt to recover equilibrium, it may emit (i) a quantum of γ-radiation, (ii) an α-particle or helium nucleus, (iii) a β-particle or electron, or (iv) undergo fission to produce a pair of high-energy ions and some high-energy neutrons. With the exception of γ-emission, all of the approaches to equilibrium result in the production of a new atom or atoms which then act as chemical impurities in the material. Quite often, the fission fragments are, or quickly decay into, one or another of the inert gases. This impurity, having a very low tendency to enter into solid solution with metals, creates volume increases due to the formation of gas bubbles. Any fission product, irrespective of whether it is a gas or not, will cause an increase in volume if its density is less than that of the parent metal.

Not only will the fission products be energetic immediately after the fission, but additionally many of them will be electrostatically charged. Because of their greater mass, the fission products move slowly compared with a neutron of the same energy and, in the case of the ions resulting from fission, their electrostatic charge will interact with other nuclei and electrons and the fission particle will quickly be brought to rest. The fact that fission fragments are quickly brought to rest also means that their energies are dissipated in a much smaller distance than those of neutrons of similar energies. Thus, these fragments produce greater localized damage than do neutrons. Much of the damage will result in displaced atoms. A neutron or fragment producing the first atom displacement is said to have produced a 'primary knock-on' and high-energy atoms resulting from such collisions may then produce secondary knock-ons.

Both primary and secondary knock-ons result in the creation of vacant lattice sites and interstitial atoms, but much of the energy is dissipated as heat. The amount of heat to be dissipated can be large in scale, equivalent to a temperature of the order of 4,000°C., even though it disperses very rapidly, and it has been suggested that around a collision area

the material melts and freezes again, rapidly forming a displacement or thermal spike. During this process, the atomic lattice becomes 'shuffled' locally and many of its defects are eliminated. The region freezes back on to its lattice containing a few lattice defects. Even so, with high-energy spikes such as result from the action of fission fragments in uranium, a considerable amount of lattice damage accumulates in time.

Annealing of radiation damage

When a thermal spike occurs, some of the lattice defects are eliminated by what may be termed self-annealing. Also, other thermal spikes in the vicinity of defects from a previous thermal spike may produce annealing and this may be termed radiation annealing. Finally, ordinary thermal annealing can be employed to eliminate more defects. Self-annealing and radiation annealing can never be completely successful in eliminating radiation damage because both are associated with radiation-damage production. The thermal annealing of radiation-damaged material is a complex process not yet fully understood, though the fundamental tendency for interstitials and vacancies to diffuse and cancel out exists. It seems fairly certain, however, that the movement of interstitials and vacancies is by no means equally shared. Interstitials have a greater urge to move than vacancies, because the lattice strain surrounding the former is considerably greater than that surrounding a vacancy.

Even when the point defects have been annealed away, some traces of radiation effects remain, and metals do not usually fully recover until much higher annealing temperatures are reached than are needed to cancel out most of the point defects.

Alternatives to the melt/freeze spike theory

Although it is probably the easiest mechanism to picture, the melting of the region of a thermal spike, followed by freezing back on to the surrounding lattice, may well be an over-simplification of the mechanism of neutron damage. It is doubtful if the concepts of melting as visualized under normal conditions up to temperatures of 2,000°C. can be applied to temperatures which theory predicts should be of the order of several thousands of degrees, in operation for very short times and over distances of a submicroscopic scale.

Most of the lattice disorder is produced by moving interstitial atoms at the end of a cascade of knock-ons which have sufficient energy to knock other atoms into interstitial positions but not enough to avoid being caught in the vacancies so created. In this way it is possible to picture, at the beginning of a thermal spike, both interstitials and vacancies; the interstitials then moving ahead and, as the total energy of the spike runs down, the late interstitials getting caught in the vacancies created by their final collisions. The last atoms leaving these vacancies come to rest in interstitial positions some distance from the vacancies (which balance them in numbers) created early in the spike.

Another suggestion refers to thermal stresses around a spike perhaps being sufficient to cause plastic flow locally and that this may be the source of disordering.

Radiation effects on uranium

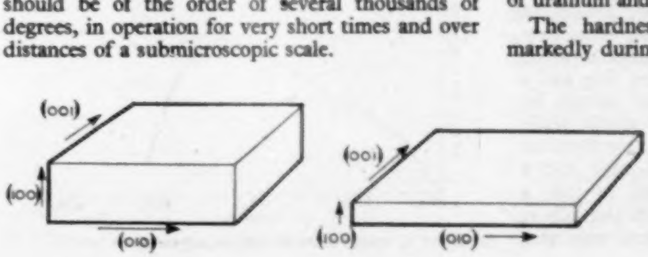
Much of what has been described so far in this section could be applied equally well to fissile or non-fissile materials. Radiation damage in solid fissile materials is, in general, more extensive than in non-fissile materials. The fissile materials are as close as possible to the source of radiation because it emanates from them and, in addition, they are concerned with the production of fission fragments. Non-fissile materials receive both neutron and fission fragments at 'second-hand.' By far the greatest experience of irradiation effects on fissile materials has been gained from uranium.

As one would expect, the amount of damage to uranium increases with time and with the strength of the neutron irradiation; the neutron flux. The kind of damage and its extent are also dependent on the physical state of the uranium and its temperature.

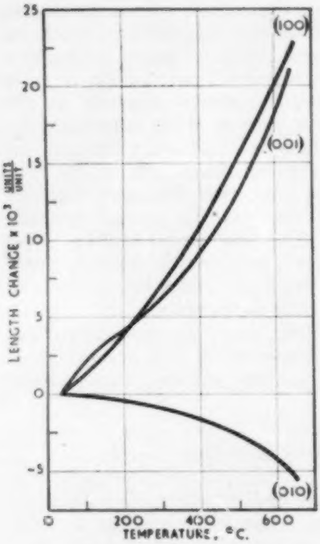
An example of short-term irradiation is given by the fact that the stress/strain curve of pure uranium exhibits an appreciable elastic limit after irradiation but not before (fig. 17).

Long-term irradiation increases the elastic limit still further and there is evidence that the ultimate tensile strength decreases. Thus it would appear that ultimately radiation damage and in particular fission products severely reduce the ductility range of uranium and it becomes quite brittle.

The hardness of annealed uranium increases markedly during irradiation. A 0·1% burn-up of



19 *Radiation growth of uranium*



20 *Radiation growth of uranium*

the uranium atoms results in a hardness increase from about 215 D.P.N. to 315 D.P.N. (fig. 18).

The thermal conductivity of uranium, which is important from a reactor heat transfer point of view, decreases during irradiation and electrical resistivity increases.

The external effects of irradiation on uranium depend on the temperature of the material. Below about 450°C., 'growth' results; above 450°C., 'swelling' results.

Radiation growth of uranium

A single crystal of uranium subjected to irradiation would change shape considerably by extending along its [010] axis, contracting on the [100] axis and leaving the [001] axis substantially unaltered (figs. 19 and 20). This growth can take place at constant temperature and should not be confused with growth due to thermal cycling. If a polycrystalline bar of uranium with crystals having a preferred orientation [010] along the length of the bar is irradiated, the growth will still occur. The bar will grow longer and decrease in diameter. Under the most appropriate conditions for growth, pronounced [010] crystal direction orientation along the length of the bar, a high neutron flux and a temperature of 200°C., the length can increase by 100% for a 0·2% burn-up of the available fissile atoms. The growth is proportional to the burn-up (ratio of fissioned atoms to total atoms), and a temperature of about 200°C. appears to give a maximum effect (fig. 21). The growth rate falls at temperatures over approx. 200°C., and may also fall at lower temperatures, but this is uncertain.

Growth of α-uranium during burn-up follows the law that the logarithmic strain is proportional to burn-up, or

$$G = \frac{\ln (L/L_0)}{\text{ratio number of fissions to number of atoms}}$$

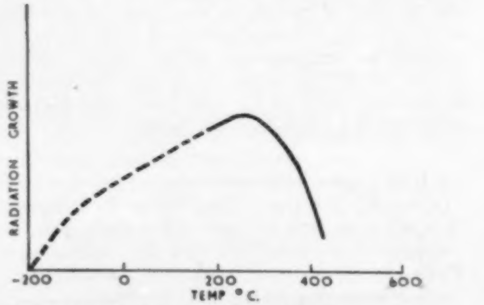
where G is the growth constant due to irradiation; L_0 the initial and L the final length. For small elongations, this reduces to $G = \dfrac{\%\ \text{growth}}{\%\ \text{burn-up}}$. G in the temperature range 50–200°C. is about 400–850 so that a length of cold-rolled uranium rod would roughly double for a 0·2% burn-up.

The growth rate G of uranium increases with the amount of cold work on the metal up to at least 70% reduction in area. Growth involves little increase in volume in contrast to swelling, which leads to large increases in volume and is not particularly directional in its result. The actual decrease in density and corresponding volume increase experienced in uranium undergoing irradiation growth is about 3% per 1% atomic burn-up.

Wrinkling

At the surfaces of uranium bars changes in the dimensions of individual grains can take place more freely than they can in grains at the core of the bar. Particularly when some of the grains have their [010] directions oriented normal to the surface and when the grain size is large, one would expect to get surface distortions after irradiation. This effect is observed and is called wrinkling. Cast uranium is of random orientation and does not change macroscopically in dimensions on irradiation, but its large grain size does lead to surface wrinkling. An idealized sketch of the wrinkling effect is given in fig. 22.

To minimize growth it is necessary to avoid directional orientation and, as explained in a previous section, this is best achieved by a rapid



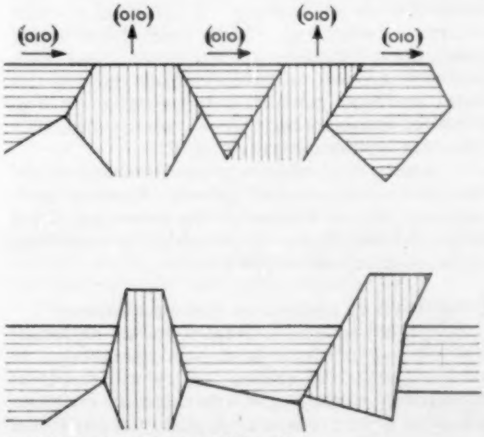
21 *Effect of temperature on radiation growth*

quench through the β/α transformation; the process known as β-quenching. The response to β-quenching of many dilute binary uranium alloys (up to 3 at.% of alloying element) has been examined and fine random grains can be achieved in many of them. The extents of growth and wrinkling are appreciably reduced by such a structure. It is also possible to achieve random fine grains by powder-metallurgy methods.

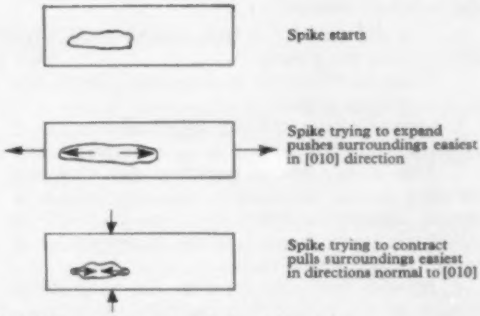
Theories of radiation growth

Two main kinds of theory have been advanced to explain radiation growth of uranium. Both are basically dependent on the anisotropic properties of the metal. One suggests that growth is the result of thermal strains existing in and around thermal spikes. The other, the point defect theory, suggests that growth is a result of the long-range migration of lattice defects created by thermal spikes.

Wyatt and Pugh,[1] in putting forward a theory of the first type, assume that the material surrounding the thermal spike is in compression during the intense heating period. Plastic deformation occurs preferentially in the [010] direction of the crystal because of the low compression yield stress in this direction. Cahn[2] showed that below 450°C. the [010] crystal axis is associated with a low yield point in compression, although in tension the yield point is relatively high. The reverse effect, high compression yield point and low tensile yield point were found in directions normal to the [010] direction. Thus, in the cooling cycle of the thermal spike, the local compressive stresses are replaced by tensile stresses and the uranium then deforms plastically in a direction normal to the [010] direction. The net result of these processes is growth in the [010] direction (fig. 23).



22 *Idealized sketch of wrinkling effect*



23 *Spike theory for irradiation deformation*

Within a mass of polycrystalline uranium, the extension is accompanied by the gradual distortion of the grains, elongated in the direction of growth.

The main objection to this type of theory is that the lifetime of the thermal spike is short, and very little is known about such high rates of stressing so that it is taking a lot for granted to assume that deformation processes proceed as under normal conditions.

The other type of theory is illustrated by that due to Siegle and Opinsky, who suggested that the shape change of uranium occurs by anisotropic diffusion of interstitial atoms and vacancies. The vacancies are assumed to diffuse along [100] axes which results in contraction and the interstitials diffuse along [010] axes resulting in expansion when the interstitial or vacancy runs out at a grain boundary. Alternatively, it has been suggested that vacancies and interstitials segregate preferentially to dislocations with suitable vectors, giving the same end result.

Cottrell[3] has summarized some of the arguments for and against both theories.

Spike theory

1. Thermal stresses give adequate driving force for growth.

2. Explains growth fall off at high temperatures by rapid relaxation of small high-strain regions at such temperatures.

3. Does not explain why rate of growth falls off at low temperatures. (In the light of recent work this may no longer be a valid objection since it is not certain that growth rate does fall with decreasing temperatures.)

4. Does not explain why the [001] axis remains unchanged by irradiation.

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[1] International Conference, Peaceful uses of atomic energy, 1955, Paper 443.
[2] *Acta Met.*, 1953, **1**, 49.
[3] *Met. Reviews*, 1956, **1**, 489.
[4] *Chartered Mech. Engr.*, 1960, **1**, (3) 105.

POINT DEFECT THEORY

1. It is difficult on this basis to find an adequate driving force for growth.
2. Diffusion of defects is extremely selective and on a very large scale.
3. Rate of growth at low temperatures explained by low mobilities of defects at such temperatures.
4. This theory has to postulate that there are sufficient thermal vacancies at high temperatures to capture interstitials before they can contribute to growth, in order to explain the disappearance of growth at high temperatures.
5. As with the spike theories, the point defect theories do not explain why the [001] axis remains unchanged.
6. Grain size would be a factor and grain boundaries would act as sinks.

These two basic arguments for explaining radiation growth are still thought possible, but neither is yet resolved. A further theory has since been proposed by Cottrell[4].

Effect of annealing and of texture

When uranium specimens having a texture produced by cold-working α-uranium are β- or γ-annealed, the texture is almost completely removed and the growth rate falls appreciably, often to less than a tenth of that before annealing. The higher the rolling temperature of the uranium bar, the less the growth, which is also consistent with the annealing effect.

If a bar has texture but there are slight differences in texture in different sectors of the bar, the tendency towards irradiation growth results in warping.

Swelling

The growth mechanism can be said to operate up to a temperature near 500°C. but at temperatures above about 400°C. an additional mechanism operates. Impurity atoms arise from fission of uranium and the transmutation of U_{238} to Pu_{239}. At these temperatures, development of gas pockets in the uranium becomes evident. This results in a change in volume and is termed swelling.

Because of the fission process, foreign elements are produced in the metal lattice. Some of these elements will be, or will decay radioactively to, the inert gases, mainly xenon and krypton. A 1% burn-up of 1 cm.^{3} of uranium gives 4·73 cm.^{3} of gas, calculated at n.t.p., but most of this will be contained at high pressure so the uranium will not expand by 473%. However, the solubility of the inert gases in solid uranium is extremely small and pockets of gas will be formed. It was thought at one time that the gases might diffuse out to the external surface of the uranium during service in a reactor and so escape without causing much swelling. In practice, only a small fraction of the gas does diffuse out at reasonable operating temperatures. Apparently, temperatures near the melting point of uranium are necessary to remove a significant amount of fission gas.

After prolonged irradiation at high temperatures, the amount of gas voids in uranium is sufficient to cause a large amount of swelling, even as much as 50% at 800°C. where the metal is plastic in the γ-phase region. The microstructure of the irradiated metal shows a large amount of gas bubbles. To contain the gas in irradiated uranium without excessive swelling obviously requires a high creep strength at high temperatures. A ductile material accommodates itself to the internal pressure by swelling but brittle material might be expected to rupture from a large pressure build-up. Even in a brittle material swelling appears to precede rupture.

Swelling rate starts linearly when plotted against temperature but the curve breaks away catastrophically for relatively high temperature. The swelling rate is not markedly affected by alloying elements but some inclusions do affect the nucleation of bubbles. The degree of swelling corresponding to burn-up is measured by an S value which is defined as

$$S = \frac{\%\text{ change in volume on irradiation}}{\%\text{ atom burn-up}}.$$

In the range 400–800°C., after ranging from 0·1–0·4% burn-up, S values of from 10–400 have been reported. The swelling rate is linear up to about 0·5% burn-up but becomes catastrophic thereafter.

Control of growth and swelling

Growth can now be controlled to a large extent. This control is achieved by careful heat treatment, giving small grains free from directionality as a result of β- or γ-quenching. A fine grain size also minimizes wrinkling. Some alloying elements assist the production of fine grains and thus minimize surface wrinkling. Other alloying reduces preferred orientation and restricts growth. Uranium-molybdenum alloys are particularly attractive in restricting swelling.

It is not yet possible to control swelling to the same extent as control of growth. External pressures can provide a restraint, but something of the order of 6,000 lb./sq. in. is needed at a working temperature of around 500°C.

Irradiation of plutonium and its alloys

If the behaviour of uranium is any criterion, attempts to irradiate pure solid plutonium to produce large heat release rates would result in extraordinary shape and volume changes. For these and other reasons it is unlikely that pure plutonium

continued on page 426

Electron beam welding

THE ELECTRON BEAM is fast gaining recognition as a unique, high-vacuum heat source for processing materials, according to Mr. Clyde M. Adams, jun., of Massachusetts Institute of Technology, writing in *Journal of Metals*, May, 1960. It is finding application in the drilling, cutting, refining and welding of metals and non-metals, and showing promise in coating, cladding and casting. First applied to welding by K. Steigerwald, of Carl Zeiss, in West Germany about 1950, several U.S. firms are currently developing and manufacturing electron beam welding equipment.

The electron beam is unique as a processing heat source by virtue of its intensity (over 5,500°C.), focusing ability and high vacuum (0·03 – 0·05 μ) operation.

Operation

The principle of operation is that of the cathode-ray tube, wherein a heated tungsten filament is the cathode from which emitted electrons are accelerated toward an anode, using a potential difference of 5,000 – 150,000 volts. In some welding equipment the anode is the workpiece itself, an arrangement common to many zone-refining or drip-melting operations. However, recent equipment has incorporated an integral ring-shaped anode through which most of the electrons are accelerated, and after leaving the region of steep potential gradient they travel at constant velocity toward the workpiece. The tendency for the beam to diverge electrostatically after passing through the anode is overcome by electromagnetic or electrostatic focusing. The workpiece and the anode are usually at the same (ground) potential.

There are two major reasons for having the anode separate from the workpiece: (1) filament life is improved, not only because the filament is geometrically remote from the workpiece—which is the primary source of contamination—but also because there is no electrostatic field to accelerate the positive ions produced by bombardment of the workpiece toward the filament; and (2) operative control is improved, since the electron beam can be directed within recesses or re-entrant angles in the workpiece without seeking the shortest path.

There is also a choice to be made as to the type of focusing employed. *Electromagnetic* focusing accords some advantages in circuitry and control, but for high-power operation the focusing coils are necessarily somewhat massive and require water cooling. In *electrostatic* focusing a secondary circuit is required to maintain the relatively low positive-potential of the focusing apertures, but these apertures may be of light construction and render more feasible the movement of the gun for automatic welding within the vacuum chamber.

Joint preparations and welding procedures are still somewhat primitive, primarily because automatic wire-feed mechanisms have not been incorporated into electron beam equipment. To date simple co-fusion of the members to be joined has been the rule, with filler, if any, being first placed along the intended seam. There is no reason to doubt that cold-feed metal techniques eventually will be applied to electron beam welding, although more quantitative information on the over-all thermal characteristics of the beam as a moving heat source must precede the evolution of firm welding procedures.

There is some controversy as to the optimum voltage range for electron beam equipment. For a given power input, the higher the voltage, the narrower is the heat source and the deeper the penetration. Thus high voltage looks attractive for drilling, cutting or joining of thick members. (The deep, narrow fusion zones produced at very high voltages bear some similarity to brazed joints.) At the other extreme, relatively low potentials (5,000—10,000 volts) can be used quite successfully for refining operations in which focusing is relatively unimportant. Weld fusion zones of shapes similar to those produced in permanent electrode arc welding are obtained in the range of 15,000–30,000 volts and 1–8 kW. For welding, the low-voltage equipment is attractive from several standpoints: (1) low-cost power supply, (2) short wave-length X-rays are not produced, and (3) equipment and insulation are substantially less massive.

Applications

The intensity of the heat source and the purity of the environment have directed much current attention to welding reactive and refractory metals. In addition, the process deserves attention for application to ultra-high-strength steels in which the complete absence of hydrogen is so essential to the consummation of a successful weld. Some difficult pneumatic problems have been solved using the electron beam welder for encapsulation; in fact, the biggest current commercial application is in sealing nuclear reactor fuel elements. Many of the most attractive characteristics have yet to be exploited. For example, by defocusing, the beam can be used for pre- or post-heat treatment in association with welding and offers much potential for vacuum brazing.

NEWS

Leybold-Elliott Ltd.—Elliott-Automation in high-vacuum field

A statement by Elliott-Automation Ltd. announces that a joint company, Leybold-Elliott Ltd., is being formed by Elliott Bros. (London) Ltd. and Leybold's of Cologne, considered the world's largest group of high-vacuum engineers.

Leybold-Elliott Ltd. will be a British company with an initial issued capital of £100,000 in which Elliott will have a majority interest. It will exploit throughout the British Commonwealth, except Canada, the industrial vacuum process equipment of both its parent groups and, by combining the complementary knowledge and experience of Leybold and Elliott, will expand the range of products still further. By a reciprocal agreement these products and those of Elliotts may be marketed in certain countries in Europe by the Leybold companies.

E. Leybold's Nachfolger of Cologne and its associated company, Leybold Hochvakuum-Anlagen GmbH., have between them established a firm position as high-vacuum specialists. The former company manufactures an extensive range of vacuum components which include high-efficiency rotary and diffusion pumps, gauges and other items of equipment used in high-vacuum industrial processes. Leybold Hochvakuum-Anlagen has specialized in the design and supply of advanced systems based upon high-vacuum techniques. Leybold equipment is extensively used in making electrical components such as valves, transformers and cables, and in steel degassing. Newly developed equipment for freeze-drying food has been so designed that by the addition of items of equipment it can be readily expanded from pilot plant to full-scale production.

The Elliott vacuum physics research laboratory at Boreham Wood has for a number of years been working in specialized fields of high-vacuum physics and has developed a range of advanced techniques which have been applied principally in developing high-power electronic radar equipment and in specialized leak-detection installations for inspection, health monitoring and quality control.

The new company, Leybold-Elliott, will take over the representation of the Leybold companies' interests in this country for industrial equipment from Leybold Vacuum Sales Ltd. The latter company's United Kingdom agency for physics teaching equipment manufactured by Leybold in Germany will be continued under existing management by a successor company, Scientific Teaching Equipment Ltd.

Czechoslovakian delegation visit Garringtons Ltd.

Amongst the many important visitors which Garringtons have been pleased to entertain at their works in Bromsgrove was a delegation of executives and technicians from the Vithovicke steelworks at Ostrava in Czechoslovakia.

The visit to this country was arranged through the British Iron and Steel Federation, and the party included in its itinerary tours of important organizations in this country connected with the steel industry.

Among the many aspects of steel forgings which the visitors were able to see was the production of components for automobile, aircraft, ship building, railway stock, agricultural implements and mining equipment. The tour of the factory included the die shop, the heavy hammer forge (comprising hammers from 4,000 to 18,000 lb. falling weight), the press forge (with presses from 500 to 4,000 tons capacity, equipped with Garringtons' induction heating), the hand tool division, the agricultural implement shop, the precision forge division (producing jet engine compressor and turbine blades in addition to commercial forgings), the laboratory, the production control department and the induction heating division, including the new extension now under construction.

Mr. Reinl, on behalf of the visitors, said that they were very impressed by the layout and methods of production and most interested in their application of electrical induction heating.

It is appropriate that Mr. G. D. Phillips, a director of Garringtons Ltd. and general manager of the induction heating division, should be the host to the party on this occasion as he is by no means a stranger to Czechoslovakia, having previously entertained a trade delegation from that country and also conducted business negotiations for Garringtons at Strojimport and at the Brno International Fair.

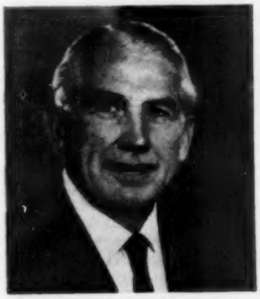
Members of the Czechoslovakian party with Mr. G. D. Phillips are here seen viewing a piece of electric induction heating equipment designed and built by Garringtons Ltd. for the surface hardening of crawler tractor track links in the company's finished products division. From left to right: Mr. J. Kratky, Mr. L. Damek, Mr. F. Reinl, Mr. G. D. Phillips and Mrs. M. Kosarova.

PEOPLE

THE FIRST AWARD of the newly created Ellis Medal for Works Management was made to **Mr. W. Huddleston,** of the Atomic Staff of the Springfields Atomic Factory, Salwick, Lancs., at last month's meeting of the Preston Branch of the Institution of Works Managers.

The Ellis Medal commemorates the work of John Milton Ellis, F.I.W.M., whose unstinted service helped to establish the I.W.M. training course, a course now offered by more than 20 technical colleges throughout the country and attended by nearly 500 students annually. The newly instituted medal will be awarded annually to the I.W.M. student, under the age of 30, who, having qualified at the end of the I.W.M. two-year course in works management, satisfies the assessors that, besides reaching the appropriate standard of competence, he has most fully appreciated the practical implications of the training he has received in the art and science of works management.

Mr. Alfred Ratcliffe has been appointed a director of Metals Division, Imperial Chemical Industries Ltd., and a joint managing delegate director of Marston Excelsior Ltd., a subsidiary company of I.C.I. At Marston Excelsior he succeeds Mr. W. Robson, who retired last month. Mr. Ratcliffe, who is 58, will also join the board of another subsidiary, Lightning Fasteners Ltd. For the past nine years Mr. Ratcliffe has been production director, and latterly also engineering director, of I.C.I. Salt Division.



Mr. A. Ratcliffe

Graduating at Manchester University in mechanical engineering, Mr. Ratcliffe joined Buxton Lime Firms Ltd. (now part of I.C.I. Alkali Division) in 1929, where he was concerned with the mechanization of the limestone quarries. In 1950 he joined I.C.I. Salt Division as deputy chief engineer and the following year was appointed a director. In the last few years there have been far-reaching changes in the field of salt production, and Mr. Ratcliffe has been responsible for introducing new systems for handling and storing salt. He has been responsible for the development, expansion and re-equipping of the rock salt mine to meet greatly increased demands. Work study techniques have been widely applied to production planning and control.

Mr. Ratcliffe is chairman of the I.C.I. Transport and Materials Handling Committee. He is a member of the Institution of Civil Engineers and the Institution of Mechanical Engineers.

Mr. J. F. Stanners, B.SC., has succeeded Dr. J. C. Hudson, who has just retired, as Head of Corrosion Research in the Chemistry Department of BISRA. He was educated at the Royal Grammar School, High Wycombe, and at Birkbeck College, London, where he gained the degree of B.Sc. (Special) in chemistry in 1944. From 1940 until 1945 Mr. Stanners was engaged as an analytical and research chemist in work on the measurement of radio-activity at the research laboratories of Thorium Ltd. (now the Radio-chemical Centre) at Amersham. He then joined the staff of the Corrosion Committee of the Iron and Steel Institute, transferring to BISRA, with Dr. Hudson, when this committee was taken over by the Association. Mr. Stanners has acted for the last eight years as deputy to Dr. Hudson and represents the Association on the Technical Panel of the Joint Committee for the Co-ordination of the Cathodic Protection of Buried Structures. He recently presented papers at two corrosion conferences in America.

Mr. J. F. Stanners

Mr. E. E. White, F.R.I.C., A.M.I.M.M., F.Z.S., M.I.INF.SC., has been appointed Head of the BISRA Corrosion Advice Bureau. He was educated at the Sir John Cass Foundation School, the City of London College and King's College, University of London. In 1935 he became an assistant chemist with Carless Capel and Leonard and, in 1937, moved to John Ismay & Sons Ltd. to take up a position as a chemist. From 1940 until 1949 he was senior chemist and metallurgist with Plessey & Co. Ltd., and it was here that he first became interested in the problem of corrosion. After a period as a full-time lecturer in applied chemistry and metallurgy at Northampton Polytechnic, Mr. White was appointed in 1950 as the technical secretary of BISRA's Corrosion Committees and Chemistry Department, which post he still retains. In

Mr. E. E. White

1954 he was appointed secretary of the newly formed Corrosion Advice Bureau.

Since 1959 Mr. White has been the chairman of the Education Panel of the Corrosion Group of the Society of Chemical Industry.

Mr. Robson, who has retired from his directorship of Metals Division, I.C.I. Ltd., began his career with I.C.I. in 1927, when he joined the Engineering Department of Billingham Division, and for six years from 1934 was manager of the Division's Central Services Section. In 1940 he went to Canada with a mission, headed by Dr. Higson, which was responsible for erecting chemical plants for the Canadian Government. On his return a year later, Mr. Robson was in charge of the development and manufacture of special weapons at that time undertaken by I.C.I. In 1944 he came to London as buying manager for engineering supplies with I.C.I.'s Central Purchasing Department. From 1947, under Sir Ewart Smith, he formed and ran the Engineering Services Department, which co-ordinated a number of engineering activities in the company. In 1952 Mr. Robson joined the Board of Metals Division and a year later became resident managing director of Marston Excelsior Ltd. at Wolverhampton. In 1954 he went out to Egypt with the mission which investigated the possibilities of civilian contractors operating and maintaining the Suez Canal base. Later he was nominated as the I.C.I. representative on the governing body of Suez Contractors Services Co. Ltd. and was chairman of the I.C.I. subsidiary, Suez Contractors (Ammunition) Ltd.

Mr. Robson is a member of the Institution of Mechanical Engineers.

Mr. J. M. Mitchell (president of Alcoa International Inc.) and **Mr. M. J. S. Clapham** (chairman of I.C.I. Metals Division) have been appointed directors of Almin Ltd.

Mr. W. Brining, Mr. J. M. Graham (directors of Almin Ltd.), **Mr. J. M. Mitchell** and **Mr. S. W. Weysom** (deputy treasurer, I.C.I.) have been appointed directors of Imperial Aluminium Co. Ltd.

Mr. E. H. S. van Someren has recently joined the British Welding Research Association as a principal scientific officer and is to work on fundamental studies on the physics of the welding arc by optical observations. He will be joining a team which includes mathematicians and metallurgists. Since graduating from London University with a special degree in chemistry, Mr. van Someren has worked in the artificial silk industry, with non-ferrous metals in Birmingham, Copenhagen and Odda, and in the photographic industry in London. Since 1958 he has been in the Research Department of Murex Welding Processes Ltd. Mr. van Someren is a member of the Institute of metals and of the Institute of Welding, a Fellow of the Institute of Physics and Physical Society, and an associate of the Royal Photographic Society.

OBITUARY

The directors of the Mond Nickel Co. announce with deep regret the death of their president, **Mr. George Archer,** C.M.G. After a long period of indifferent health Mr. Archer was taken ill in his office and died in Westminster Hospital on September 20.

Mr. Archer, who was appointed president in July of this year, had been chairman of the company and its subsidiary, Henry Wiggin & Co. Ltd., since July 1959. He joined the board of the Mond Nickel Co. in 1948 and became sales director in 1952 and managing director in 1955.

Born in Manchester in 1896, Mr. Archer was educated at King Edward VII School, Lytham. He entered the Civil Service in 1913, served in the R.N.V.R. from 1915 to 1919 and afterwards in various departments, including Customs and Excise and the Import Duties Advisory Committee. At the outbreak of war in 1939 he was transferred to the Raw Materials Department in the Ministry of Supply, and in April 1941 joined the Ministry's Mission in Washington. Soon after the formation in 1942 of the British Raw Materials Mission he was appointed Secretary-General and became head of the Mission in 1945. He was also U.K. Secretary of the Combined Raw Materials Board. In 1945, in recognition of the above services, Mr. Archer was made C.M.G.

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METALLURGIST required in the laboratory of a light engineering company to assist in the investigation and development of new materials and processes in connection with the manufacture of diesel engine accessories. The post offers good opportunities to a person who has had a sound general training in metallurgy, gained either through experience in industry or by attending a recognized course. Applicants should preferably be in the age group 21-25, qualified at least to O.N.C. level and prepared to study for higher qualifications. Good pension scheme. Five-day week. Write in full to Staff Employment Officer, C.A.V. Ltd., Warple Way, Acton, W.3.

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REQUIRED URGENTLY. Secondhand Massey, preferred drop hammer—10 cwt. capacity, also trimming press. Box RE 131, METAL TREATMENT AND DROP FORGING.

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ONE 7-CWT. PATTINSON DROP STAMP. Arranged for motor drive. Price and particulars from Thos. C. Wild Ltd., Vulcan Works, Tinsley Park Road, Sheffield 9. Telephone 42471.

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Mr. Robson, who has retired from his directorship of Metals Division, I.C.I. Ltd., began his career with I.C.I. in 1927, when he joined the Engineering Department of Billingham Division, and for six years from 1934 was manager of the Division's Central Services Section. In 1940 he went to Canada with a mission, headed by Dr. Higson, which was responsible for erecting chemical plants for the Canadian Government. On his return a year later, Mr. Robson was in charge of the development and manufacture of special weapons at that time undertaken by I.C.I. In 1944 he came to London as buying manager for engineering supplies with I.C.I.'s Central Purchasing Department. From 1947, under Sir Ewart Smith, he formed and ran the Engineering Services Department, which co-ordinated a number of engineering activities in the company. In 1952 Mr. Robson joined the Board of Metals Division and a year later became resident managing director of Marston Excelsior Ltd. at Wolverhampton. In 1954 he went out to Egypt with the mission which investigated the possibilities of civilian contractors operating and maintaining the Suez Canal base. Later he was nominated as the I.C.I. representative on the governing body of Suez Contractors Services Co. Ltd. and was chairman of the I.C.I. subsidiary, Suez Contractors (Ammunition) Ltd.

Mr. Robson is a member of the Institution of Mechanical Engineers.

Mr. J. M. Mitchell (president of Alcoa International Inc.) and **Mr. M. J. S. Clapham** (chairman of I.C.I. Metals Division) have been appointed directors of Almin Ltd.

Mr. W. Brining, Mr. J. M. Graham (directors of Almin Ltd.), **Mr. J. M. Mitchell** and **Mr. S. W. Weysom** (deputy treasurer, I.C.I.) have been appointed directors of Imperial Aluminium Co. Ltd.

Mr. E. H. S. van Someren has recently joined the British Welding Research Association as a principal scientific officer and is to work on fundamental studies on the physics of the welding arc by optical observations. He will be joining a team which includes mathematicians and metallurgists. Since graduating from London University with a special degree in chemistry, Mr. van Someren has worked in the artificial silk industry, with non-ferrous metals in Birmingham, Copenhagen and Odda, and in the photographic industry in London. Since 1958 he has been in the Research Department of Murex Welding Processes Ltd. Mr. van Someren is a member of the Institute of metals and of the Institute of Welding, a Fellow of the Institute of Physics and Physical Society, and an associate of the Royal Photographic Society.

OBITUARY

The directors of the Mond Nickel Co. announce with deep regret the death of their president, **Mr. George Archer,** C.M.G. After a long period of indifferent health Mr. Archer was taken ill in his office and died in Westminster Hospital on September 20.

Mr. Archer, who was appointed president in July of this year, had been chairman of the company and its subsidiary, Henry Wiggin & Co. Ltd., since July 1959. He joined the board of the Mond Nickel Co. in 1948 and became sales director in 1952 and managing director in 1955.

Born in Manchester in 1896, Mr. Archer was educated at King Edward VII School, Lytham. He entered the Civil Service in 1913, served in the R.N.V.R. from 1915 to 1919 and afterwards in various departments, including Customs and Excise and the Import Duties Advisory Committee. At the outbreak of war in 1939 he was transferred to the Raw Materials Department in the Ministry of Supply, and in April 1941 joined the Ministry's Mission in Washington. Soon after the formation in 1942 of the British Raw Materials Mission he was appointed Secretary-General and became head of the Mission in 1945. He was also U.K. Secretary of the Combined Raw Materials Board. In 1945, in recognition of the above services, Mr. Archer was made C.M.G.

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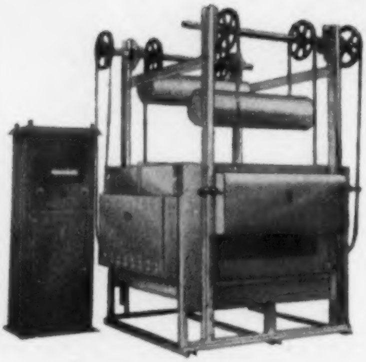

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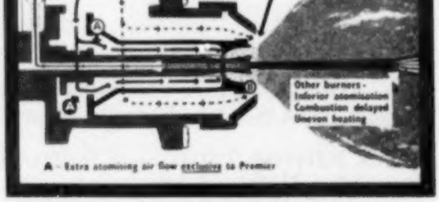

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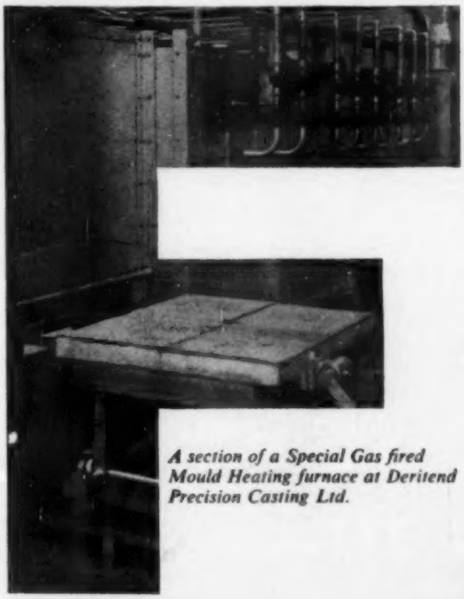

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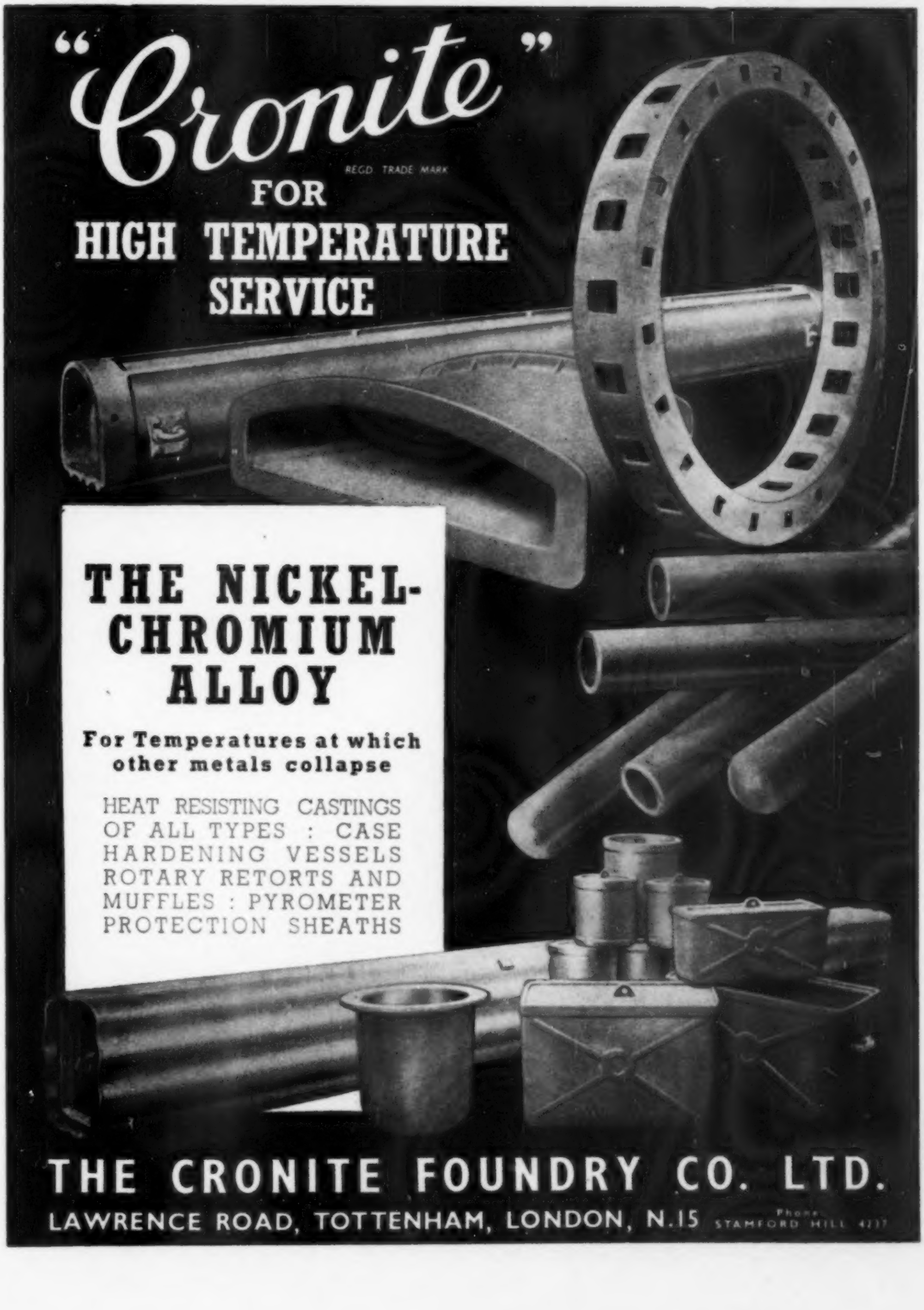
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